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THE COST OF DECOMMISSIONING
URANIUM MILL TAILINGS

by

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ABSTRACT

All uranium mining and milling facilities have a finite life of operation and, at some point in time, require decommissioning. A part of this decommissioning is the close-out of the waste management or tailings area. In Canada, at present, the objectives of decommissioning the waste management area are to ensure that the facility is left in such condition that no physical, chemical or radiation risk of an unacceptable nature remains. In order to ensure this, mining and milling companies are required to carry out a decommissioning program and to demonstrate, through monitoring over a period of years following decommissioning, that the site is behaving as predicted and is currently or will not in the foreseeable future present an unacceptable risk to the human or natural environment. The present concept in Canada is that, following a reasonable time during which the site has been shown, through monitoring, to be behaving in an acceptable manner, the responsibility for the site and its subsequent monitoring would revert to the Crown. At present, there is a need for industry to know what the costs of decommissioning and post-decommissioning monitoring are likely to be and for government to know what the costs of continuing surveillance are likely to be.

This report identifies several key operations that are commonly carried out during decommissioning of tailings areas in the Canadian environment. These operations are unit costed for a generic site to provide a base reference case. The unit costs have also been scaled to the quantities required for the decommissioning of four Canadian sites and these scaled quantities compared with site-specific engineering cost estimates and actual costs incurred in carrying out the decommissioning activities. Variances in costing are discussed. The report also recommends a generic monitoring regime upon which both short- and longer-term environmental monitoring costs are calculated. Although every site must be addressed as a site-specific case, and monitoring programs must be tailored to fit a specific site, it would appear that for the conventional decommissioning and monitoring practices that have been employed to date, costs can be reasonably estimated when site-specific conditions are taken into account.

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RÉSUMÉ

Toutes les installations minières nécessaires à l'extraction de l'uranium ont une durée de vie limitée et, en conséquence, elles doivent être désaffectées. La fermeture des lieux d'entreposage de déchets ou d'un parc à résidus doit aussi être comprise dans le processus de désaffectation. Les objectifs canadiens actuels en matière de désaffectation de parcs à résidus visent à assurer que les lieux soient laissés dans un état tel qu'ils ne présentent aucun risque inacceptable, qu'il soit physique, chimique ou radioactif. Pour atteindre cet objectif, les compagnies minières doivent mettre sur pied un programme de désaffectation et démontrer par une surveillance périodique s'étendant sur plusieurs années après la désaffectation, que les conditions mesurées sur le site se conforment aux prédictions et que ce dernier ne présente pas, ni ne présentera dans le futur, de risques inacceptables pour l'humain ou l'environnement naturel. Le principe directeur canadien sous-entend que si après une période de temps raisonnable où un site s'est avéré présenter un comportement acceptable, ceci lors d'un programme de surveillance, que la responsabilité pour ce site et la surveillance subséquente soient alors transférées à la Couronne. On dénote actuellement chez l'industrie un besoin de connaître la nature et l'ampleur des coûts associés à la désaffectation et à la surveillance subséquente et chez le Gouvernement un besoin de connaître les coûts associés à la surveillance à long terme.

Ce rapport identifie plusieurs opérations cruciales couramment réalisées dans le cadre de la désaffectation de parcs à résidus dans l'environnement canadien. Les coûts unitaires de ces opérations sont présentés pour un site typique afin d'établir une base de référence. Ces coûts unitaires ont de plus été correlés aux quantités impliquées dans la désaffectation de quatre sites canadiens et ces quantités ont été comparées avec les estimations des coûts d'ingénierie spécifiques pour chacun des sites et les coûts actuels effectivement encourus lors de la réalisation du programme de désaffectation. La variance des différents coûts y est discutée. Ce rapport suggère également un programme de surveillance type à partir duquel les coûts de surveillance environnementale à long terme et court termes peuvent être calculés. Bien que chaque site doive être évalué sur une base individuelle et que les programmes de surveillance doivent être conçus en fonction de la spécificité de chaque site, il semble, pour les pratiques conventionnelles de désaffectation employées jusqu'à maintenant, que les coûts puissent être raisonnablement estimés à condition que les caractéristiques spécifiques d'un site soient prises en considération.

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SUMMARY AND CONCLUSIONS

Summary

Decommissioning is the act of taking a facility out of service. In most cases, this results in the operators relinquishing environmental responsibilities and the property reverting to alternative uses. However, the potential long-term environmental implications relative to alternative uses of uranium mill tailings sites dictate special requirements. In Canada, the Atomic Energy Control Board has the Federal responsibility of ensuring the Canadian environment and people are adequately protected from detrimental effects of radiation and radionuclides that may be released from uranium mill tailings. As part of this mandate, they have commissioned the current study to investigate the amount of money that should be budgeted to decommission a uranium mill tailings site and the annual cost of maintaining institutional controls or monitoring of this facility after decommissioning.

This study reviews available data on uranium mill tailings to identify current decommissioning practices and post-decommissioning monitoring requirements. The data from these studies were used to provide a generic decommissioning approach upon which cost estimates were based. A computer spreadsheet approach was used, with unit cost estimates, to facilitate application to specific projects. This was then tested utilizing available cost information from Canadian and U.S. facilities.

Cost estimations for decommissioning of a generic 40-ha above-ground site were in the \$2.5 to \$3.75 million range, depending on site remoteness. When the spreadsheet unit costs were applied to tailings sites for which actual or mining company estimated costs are known, the variance ranged from -1 to +39%. In most cases, the higher costs estimated by generic evaluation resulted from savings due to the companies using internally available equipment or resources. This emphasized the importance of careful planning.

An all-inclusive environmental monitoring program was estimated to cost an average of \$34,000.00 per year for the first five years, reducing to \$11,000.00 annually or less thereafter. Site-specific variables will alter this cost.

A series of recommendations relative to decommissioning are presented in the report.

Conclusions

1. The generic spreadsheet approach, utilizing unit costs from the literature, provides a good initial estimate for planning of decommissioning budgets. It must be calibrated based on knowledge of the amount of initial decommissioning planning that was put into the original project design, availability of local resources and the environment to be protected.
2. Early planning of decommissioning, to optimize utilization of equipment, labour and local resources, can result in substantial savings. The siting of the tailings management facility and the availability of cover material are prime planning requirements.
3. For above-ground sites, research to plan an appropriate, site-specific revegetation program, based on tailings chemical and geochemical properties, is essential for long-term cover stability.
4. Long-term environmental protection requires a site-specific monitoring program. This is best designed based on pre-operational and operational monitoring results which serve to characterize local environmental transport and food chain pathways.
5. For conventional mining and milling operations with ore grades of less than 0.5%, and no special concerns related to acid generation or unusual trace or heavy element levels, budgets in the order of \$2 to \$4 million should be set aside to ensure a proper decommissioning activities and post-decommissioning monitoring program for a 40-ha site that has been pre-engineered to meet operational requirements. If significant decommissioning planning goes into the design and operational phase, this figure would be reduced. For facilities which mine and mill high grade ores (GT 1 to 2%) or ores containing significant (GT 1 to 2%) pyrite or unusual levels of trace elements or heavy metals, costs may be expected to be proportionately higher.

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SECTION 1

INTRODUCTION

1.0 INTRODUCTION

The growth of the uranium mining industry has resulted in a number of concerns relating to its potential for long-term environmental effects. These concerns relate in large part to the mill tailings and, in some cases, waste rock that remains after mining and milling operations cease. Many of these concerns result from the potential for release of radioactive and stable elements which cannot be extracted from the ore economically. Also, a range of process chemicals are discarded in mill tailings. Mining and milling activities have changed the chemical form of many of the original ore elements and the manner in which they may potentially affect the environment. This has placed a responsibility upon the mining companies and regulatory authorities to ensure proper design of containment systems for the tailings and to monitor these over the long-term to ensure that any significant potential for release at unacceptable levels is avoided.

Decommissioning is the act of taking a facility out of service. In many industries, once a factory is decommissioned or closed, the operators relinquish all responsibilities and the site reverts to some alternative land use. The long-term environmental effects associated with the radioisotopes, heavy metals, and other potential contaminants that industrial societies produce dictates the need for long-term environmental protection planning and design as well as the need for post-decommissioning monitoring to test the results of this design.

Decommissioning has occurred at a variety of uranium mine sites in Canada, U.S.A., France, Australia, etc., with further sites in these countries as well as others requiring decommissioning in the near future. In Canada, the Atomic Energy Control Board (AECB) has the Federal responsibility of ensuring the Canadian environment and people are adequately protected from adverse effects resulting from uranium developments. This implies a responsibility for ensuring that operators plan and set aside adequate funds for decommissioning and post-decommissioning monitoring. There is no legislative requirement in Canada requiring such funds be set aside at this time. The Saskatchewan Government used to have a policy to allocate one million dollars per operating mine to a contingency fund to handle long-term unforeseen problems that may arise after decommissioning and when the Provincial Government assumes responsibilities for the site. This pertains to all operating uranium mines and mills in the province, since no mines have gone into production since the policy ended. Ontario has no such policy.

Following decommissioning, some form of surveillance may be needed until it can be adequately demonstrated that the tailings have achieved a condition of long-term stability. This may require institutional assumption of the monitoring responsibilities. For these reasons, the Atomic Energy Control Board has contracted this study to determine the amount of money necessary to decommission a uranium mill tailings site, and to provide post-decommissioning monitoring to ensure long-term environmental protection.

The actual decommissioning approach will vary with the size, location, type of ore, decommissioning infrastructure available at the mine site at the time of decommissioning and current state of technology. Variations in decommissioning approach will, in turn, dictate the most appropriate types of monitoring. Long-term monitoring requirements of decommissioning will also be partially determined by the results of the initial surveillance indicating potential changes that may occur in the tailings environment. Over the duration of the decommissioning period, and beyond, the general principle should be followed that releases of potential contaminants from the tailings will limit potential doses from radiation to "as low as reasonably achievable, social and economic factors being taken into account" (ALARA). Although stated in terms of radiation, this principle should apply to all potential contaminants.

In addition to the application of ALARA to decommissioned uranium mill tailings sites, it is necessary to give consideration to a range of both physical and chemical factors that may, in themselves, pose an unacceptable environmental risk or may have an effect on future radiation doses which may be received. Levels of potentially toxic trace elements in waters draining from decommissioned sites are, at present, adequately covered by both provincial and federal water quality standards that must be met as part of any decommissioning criteria. In order to ensure long-term post-decommissioning site stability with respect to releases of both radionuclides and stable elements, passive control systems that are not dependent upon maintenance are to be encouraged. Passive systems which result in higher levels of containment and lower levels of environmental risk through time are to be encouraged. For example, the initial placement of tailings and their decommissioning in a natural sedimentary basin, where they are likely to be covered with increasing depths of sediment over time and thus further isolated from the biosphere, may be preferable to the decommissioning of tailings in erosional environments where the release of radionuclides and metals to the biosphere is likely to

increase with time. As a general guideline in this area, an objective of decommissioning is that the releases of radionuclides or other materials, which may pose an unacceptable risk to the natural or human environment, continue to decrease with time and that the magnitude of this release does not exceed operational releases.

These general policies have been followed in guidelines set for tailings decommissioned to date. However, unless adequate consideration is given to decommissioning in the initial planning phase for tailings placement, it may not be possible to optimize decommissioning objectives with the natural site characteristics found in the local environment, such as the presence of natural sedimentary basins.

1.1 Study Objective

The objective of this study was to determine the amount of money needed to decommission a uranium mill tailings site and the annual cost of maintaining institutional controls or monitoring of this facility after decommissioning to ensure that the tailings will not present an undue risk, in the long-term, to members of the public.

1.2 Study Approach

The general approach in this study was to review available data from Canada and elsewhere in order to identify current decommissioning practices and post-decommissioning monitoring requirements for uranium mill tailings. These data have then been used to prepare a generic check list of optimal decommissioning requirements. Means (1982) unit cost estimates were then used to estimate budget costs for a generic site. These were compared to actual decommissioning costs where available. The study also formulates a generic monitoring program and its costs for planning purposes. Since a monitoring program must be both site specific and iterative, it must be kept in mind that monitoring emphasis might change as new data become available.

The approaches to decommissioning and monitoring are presented on a unit-cost basis to allow application to specific sites. Tests were run utilizing a hypothetical 40-hectares (ha) tailings site to determine the applicability of the computer spreadsheet model prepared. A comparison was made with actual decommissioning costs (where available)

from Canadian and U.S. facilities to evaluate the accuracy and appropriateness of the cost estimation techniques.

1.3 Recommendations

During the study, a number of factors became apparent relative to the use of the generic spreadsheet approach to estimation of decommissioning costs and to the comparison of the generic costs with actual or site-specific estimated costs. Many of these can result in substantial savings during decommissioning activities. For this reason the following recommendations on the optional approaches to uranium tailings decommissioning are summarized here. These points are discussed in more detail in the text.

1.3.1 Use of Generic Spreadsheet

- The generic spreadsheet provides a reasonable "first cut" at cost estimations. When compared to site specific estimates or actual decommissioning costs, it becomes clear that great differences can occur in the actual costs from one site to another. Any generic model must be calibrated. In this case calibration must be on a regional basis.

Recommendation

The spreadsheet can be used as an initial estimate of tailings decommissioning costs. As actual sites are decommissioned in different regions of Canada, the spreadsheet should be calibrated and, where necessary, unit costs revised or activities changed to upgrade the usefulness of this as a planning tool.

- The spreadsheet was designed utilizing a relatively simple program (Multiplan, copyright Microsoft). This program was run on a standard PC microcomputer with 256 K memory. Such computers are generally available to government and industry throughout Canada.

Recommendation

Copies of the spreadsheet data disk can be provided with the final report to allow its use in calculations of tailings decommissioning costs on a site-specific basis. Revision

suggestions should be solicited from users to calibrate and upgrade the accuracy of the spreadsheet.

1.3.2 Use of Site Facilities in Decommissioning

- Much of the cost of decommissioning relates to equipment and labour. These have been estimated at contractor unit costs.
- At remote areas, these decommissioning costs can escalate significantly due to lack of local supplies of manpower, equipment and materials. At the time of mine closure, there are usually available an experienced labour force (often looking for related jobs) and equipment (often already depreciated). Information from mining companies indicates the cost of decommissioning may be cut in half by careful planning to utilize these employees and equipment. Local sources of materials, such as clean waste rock, can also allow significant savings if advance planning results in proper handling and placement during mine operation.

Recommendation

Conceptual decommissioning plans should be prepared and approved well in advance of mine closure to allow planning for use of existing equipment, materials and manpower. AECB should encourage innovative, site-specific planning.

- One of the most expensive items in tailings decommissioning is cover material. Innovative planning to utilize locally available resources may save much time and money. Planning can entail such things as inventories for appropriate cover materials in the site area, stockpiling and protection of cover materials throughout operation, use of clean mine waste and blasting of native rock as available.

Recommendation

Mine operators should be encouraged to plan the use and sources of decommissioning materials well in advance of closure.

1.3.3 Revegetation

Revegetation of uranium tailings has, at times, become a problem. Toxic wastes in the tailings, lack of nutrients, particle fineness or dehydration can result in failure of revegetation. If this occurs several years after the site is closed, it can be very expensive to restore. Site-specific research is needed to identify the best species, soil conditioning, cover and fertilizer requirements. A study of successful approaches used in similar mining locations is the most cost-effective approach to revegetation planning (c.f., Kalin 1983).

Recommendation

Decommissioning planning should involve experiments to determine the most appropriate vegetative cover at an early stage. This can involve test plots on a small scale or, possibly more appropriately, could involve an on-going covering and revegetation of tailings areas during operations. It is recommended that any such research emphasize the use of vegetation native to the mill site as much as possible. A general rule in bioengineering is that only plants from sites with identical or, at least, very similar ecological conditions should be used (Schiechtl, 1980). Such plants are already adapted to the area and thus will require much less care, such as fertilizer, irrigation and protection from the local microclimate or pests. Native species are also locally available, the use of which will minimize the need for introduction of exotics, which could result in damage to the local ecological balance. Two points must be emphasized in making the selection of such plants. First, tailings are not native soils. A study of particle size, chemical and moisture regimes is a necessary first step in deciding the most appropriate species for revegetation. Second, such species must be chosen to optimize fast growth (pioneer species), long-term stability or induction of stable succession, local availability of seeds or cuttings and adaptation to the long-term microclimate of the site.

1.3.4 Monitoring Programs

- The proper design of a post-operational monitoring program is essential to ensuring the long-term protection of the local environment. Designing an appropriate monitoring program at a remote, decommissioned site, after the logistical infrastructure has been removed, can greatly decrease the cost-effectiveness of the monitoring program.

Recommendation

Environmental monitoring programs should be designed and tested in the planning and operational phases of a uranium mine and mill. The same monitoring stations, or a reduced number if operational monitoring results indicate this is appropriate, should be used in the post-decommissioning phase.

- The monitoring program discussed in Section 5 of this report is meant to be an all-inclusive approach that is designed to include all foreseeable mechanisms or environmental transport pathways that would result in long-term contamination of the environment. The program design is based on published sources (Environment Canada, 1978), as well as experience of the authors with government requirements for pre-operational monitoring of proposed uranium mine/mill sites (e.g., Brinco, Cogema, ESSO Minerals) and recently commissioned sites (e.g., Key Lake). We have also incorporated aspects of ongoing research monitoring of operating and decommissioned sites by CANMET (e.g., Elliot Lake laboratory) and the National Uranium Tailings Program (e.g., Gunnar and Lacnor sites). As such, this program is somewhat idealistic, and may contain elements not appropriate to every uranium mill tailings site in Canada.

Recommendation

Site-specific, post-decommissioning monitoring programs should be based on a cooperative review of the local environmental priorities, as well as the results of operational monitoring. The spreadsheet (Appendix 2) can then be modified to more appropriately estimate costs for a site-specific monitoring program.

SECTION 2

DECOMMISSIONING ACTIVITIES

2.0 DECOMMISSIONING ACTIVITIES

2.1 Decommissioning Objectives

The following sections summarize the major objectives which must be achieved in the decommissioning of a uranium tailings facility. The discussion also notes the different types of tailings resulting from differences in mining and milling methods and ore bodies. Such differences must be considered when designing decommissioning and monitoring plans for a specific site.

Four major concepts enter into most decommissioning plans:

- minimization of reactive surface area,
- stability, both physical and geochemical,
- establishment of a cover, and
- control of contaminant releases (radon, metals, dust, seepage, gamma radiation).

These plans are aimed at satisfying the following goals of a decommissioning strategy:

- adequate protection of health and safety of persons and protection of the environment;
- containment and isolation of wastes within a decommissioned site; and
- minimization of reliance on active institutional controls for the protection of public health and safety and for the protection of the environment.

2.1.1 Minimization of Reactive Surface Area

The release of contaminants from any tailings mass occurs through the surface area which is in contact with those parts of the environment that are capable of reacting with, and providing potential transport pathways for, these contaminants. A bare, sandy surface offers an interface for both dust and radon transfer, whereas a water-covered surface may allow diffusive transport of dissolved material to the overlying water and subsequent transport of both soluble and particulate materials by advective flow. The less the reactive surface area is exposed, the less potential there is for contaminant

generation and transfer to the open environment. The more tangible objectives of achieving geotechnical and cover stability are aimed at maintaining a low reactive surface area-environment interface. The objectives of geochemical stability and seepage control are aimed at reducing the magnitude of contaminant flux through those interfaces which exist within any given decommissioning design.

2.1.2 Tailings Stability

Physical Stability

The primary requirement is to assure the tailings mass is geotechnically stable. This applies to all above-grade tailings as well as to subgrade deposits, particularly for those operations which may propose to use deep-water disposal methods.

An initial consideration is the geographic location of the tailings site. In the Canadian environment, the potential for long-term physical or geotechnical stability can often be estimated from considerations of similar types of silty, sandy deposits found in the area. The degree to which these deposits have been eroded in the post-glacial time period can often provide clues as to potential erosion rates for a tailings mass placed in a similar environment. It is often deemed necessary or prudent to provide some degree of geotechnical reinforcement to a tailings mass to resist mass erosion and to provide protection against the consequences of seismic events.

Potential activities to enhance geotechnical stability include:

- construction or reinforcement of berms with mine waste rock, local gravel, etc.;
- vegetation and/or revegetation of berms, both old and new; this can decrease erosion and improve aesthetics;
- lowering the water table in the tailings to reduce hydraulic pressures in retaining dams where appropriate;
- construction and stabilization of diversion ditches and 'flood plain' areas to ensure that runoff events do not cause erosion of solids; and

- reinforcement of downstream small lake or pond outlets that are not bedrock controlled to reduce the probability of a 'washout' event. These may also serve as 'natural sedimentation basins', thus restricting the spatial redistribution of any eroded tailings mass. Such basins might also result in artificial 'notch points' restricting upstream erosion.

Geochemical Stability

The uranium milling process subjects the ground ore to very strong oxidizing conditions, usually in an acidic environment. Before discharge, the tailings are adjusted to a neutral or basic pH with lime. However, the chemistry of the system is still under a highly positive redox environment. By virtue of the placement of tailings in a protected environment, the penetration of oxygen into the tailings mass is usually restricted, thus creating a reducing environment. If there is a carbon source present, for example, the placement of sewage in tailings or the presence of carbonate minerals, bacteria can use the energy gradient that is present and reduce, for example, sulphates to sulphides. In the presence of oxygen near the surface, sulphides can be converted to sulphates. These types of processes are bacterially mediated. The former may lead to trace element immobilization through the production of insoluble metal sulphides, whereas the latter may lead to trace element mobilization through the production of soluble metal sulphates.

In addition to bacterially mediated geochemical instability, the redistribution of hygroscopic salts within a tailings area may lead to both geochemical and geotechnical instability. For example, in the same semi-arid climate of much of Canada's north, soluble sulphates may be dissolved by fresh meteoric waters infiltrating into recharge areas on the tailings, and then those same salts may be precipitated along with their waters of hydration in an evaporative discharge area. The presence of an abundance of soluble salts at the surface of discharge areas can result in high fluxes of total dissolved solids in runoff. The presence of high concentrations of water in these salts may contribute to unusual and unexpected frost-heaving phenomena. To date, very little effort has been expended on decommissioning controls which directly address geochemical stability questions other than the specific issue of pyrite oxidation. To date, the general approach to the latter has been one involving excess liming and the placement of barriers to restrict infiltration and oxygen penetration.

2.1.3 Cover

Because modern tailings waste management areas are engineered in such a way that mass transport from water erosion processes is highly controlled, the control of dust, prevention of oxygen penetration, release of radon and shielding from gamma radiation are probably the major concerns relating to covering of the tailings. This is of more concern near human habitation than in a remote location where the main use of cover may be to encourage vegetation, thus enhancing aesthetics and providing some degree of protection against wind erosion.

Rainfall or snow-melt waters seep into the tailings along with dissolved gasses and nutrients. In the case of pyritic tailings, the transport of dissolved oxygen may lead to geochemical instability and, in the case of all tailings, the movement of water from recharge to discharge areas can lead to the redistribution of soluble salts within the tailings, thus creating pockets of both geochemical and geotechnical instability. If the cover can divert, transpire or consume oxygen in precipitation, the acid generation associated with pyrite oxidation must decrease with time.

Ambient radon measurements have been shown to drop to background at a distance in the order of one kilometer from the edge of exposed tailings. Radon exhalation is thus of primary concern only in populated areas.

The types of cover in order of general availability in the Canadian context are:

1. mine waste;
2. sand or till;
3. clay and clay rich silt which may be used as natural liners in geotechnically stable situations;
4. bog or peat organic material which may be used as a cover in low, wet areas to encourage vegetation growth and which may act as a geochemical barrier to oxygen and nutrient penetration into the tailings; and
5. desulphidized tailings which could be used as a manufactured cover material for pyritic tailings.

The technology of floating pyrite (sulphide) from tailings has been used in South Africa for years because South Africa has no other source of sulphur to make sulphuric acid. The economics of floating sulphides in Canada involves a combination of the capital/operating costs and what one does with the pyrite concentrate produced. Canadian examples are the burning of base metal mine pyrite at Cutler at the mouth of the Serpent River on Lake Superior to produce sulphuric acid for Elliot Lake and, at Lorado (northern Saskatchewan), floating pyrite from its ore to produce sulphuric acid on site.

The economics of sulphuric acid production has been affected by a large supply of sulphur from sour natural gas in Western Canada and nickel smelters in Sudbury. These are classic examples of global economics in other resource industries affecting the economically viable options for potential decommissioning of a tailings site.

Man-made covers have been used on an experimental basis, primarily in the United States. These, which include asphalt binders or plastic membranes, have been shown to suffer from mechanical damage, high cost and the fact they require continuing attention and maintenance.

2.1.4 Seepage Control

Both quantity and quality of seepage from a tailings area is of general concern since the product can result in a net flux of a potential contaminants to the environment. This release usually occurs via the groundwater or surface water transport route. Seepage source strength is a function of the ore and the uranium circuit producing the tailings. Site-specific variations of the milling process cause differences in the tailings slurry produced. The tailings solution is the initial pore water of the tailings and thus dictates the initial source strength of the seepage.

The method of placement of tailings is important in controlling the drainage characteristics of the tailings mass, and ensuring the stability of impoundment structures. A layered placement of tailings may decrease the vertical component of seepage relative to that realized by conventional placement methods which tend to generate heterogenous flow patterns and associated interfingering sand and slime zones.

The quantity of precipitation falling on a tailings storage site and the associated water infiltration into the tailings will control, to a large degree, the quantity of seepage ultimately released from the tailings mass. It should be recognized that within any tailings area there may be seepage recharge and discharge zones where seepage water may appear as ponded water on the tailings or as surface runoff enriched in total dissolved solids.

Minimization of the amount of water entering a tailings area will obviously, in turn, minimize potential seepage releases from that facility. Consequently, where applicable, diversion of surface runoff should be a preferred option. The viability of such an option will be strongly influenced by the siting of the tailings area. Seepage can be minimized by locating tailings sites at the top of a drainage basin so that only direct rainfall goes in or through the tailings pile. This concept of minimizing the headwater drainage area is an important selection criterion.

Seepage into, and more commonly from, operating tailings areas is often controlled by low-permeability liners. Seepage from an operating tailings area is driven by the hydraulic head created by the process and other flows into it. These may fluctuate considerably with operation of process water balance adjustments, natural precipitation and runoff events, and effluent treatment operations. The hydraulic head will generally decrease naturally on the cessation of operations especially at sites in drier areas. Upon decommissioning, it may be advantageous to artificially lower the water table in the tailings mass to aid surface contouring and covering. The resultant reduction in hydraulic head decreases seepage from the tailings area, aids consolidation of the surface layers, and increases the geotechnical stability of the tailings mass. However, the reduction in the water table may also, in the case of pyritic tailings, decrease the geochemical stability of the upper meter of tailings depth.

2.2 Decommissioning of Tailing Sites

In order to achieve long-term stability of decommissioned tailings, mining companies in the past have employed a variety of management practices. The following reviews some of these management practices and their relative success. Because of the importance of the milling technology employed, a series of different mine and mill techniques is discussed.

2.2.1 Group I: Inactive tailing sites from mills that used weak acid leach (L5%)

(a) Lorado and Gunnar - Northern Saskatchewan

The ores and milling processes at these two mines were similar. Both were low-pyritic ores. Weak sulphuric acid leach solution was produced on-site. Both companies discharged the unneutralized tailings into a small lake (below grade). At Gunnar, the first lake overflowed and the tailings were decanted into two smaller lakes and, finally, into Langley Bay. Lorado discharged the mill tailings to Nero Lake.

The uranium ores found along the north shore of Lake Athabaska contained appreciable calcite. Gunnar reported 8% calcite or 160 lb/ton of ore. Lorado ores were similar and, initially, the sulphuric acid leach was set at pH 1.8 by adding all the acid to the first agitator. Acid consumption ran as high as 300 lb/ton and leach temperatures were 50°C above ambient. Lorado pioneered the stepped leach process whereby the pH of the leach was brought down gradually, i.e., No. 1 agitator to pH 4.5, No. 2 - 3.5, No. 3 - 2.5 and final agitators to 2.0 - 1.8. There would appear to be active geochemical processes occurring in both the tailings from Lorado and Gunnar. The tailings surfaces are revegetating in some of the wetter areas. In dry, old beach areas, however, the tailings are still unstable because of wind action, and vegetation is very slow to establish. Decommissioning activities at both of these sites were minimal.

(b) Madawaska - Central Ontario

The other Canadian, weak acid leach mill was at Madawaska. This mill was operated, from 1957 to 1964, by Faraday Uranium Mines Limited. It was reactivated by Madawaska Mines Limited in the 1970's and operated from 1976 to 1982. Uranium, from the low-pyritic ore, was extracted by a weak acid leach/ion exchange process.

When Madawaska's buyer of uranium concentrate discontinued receipt of their product, Madawaska had to suspend milling operations in July 1982 and went into a care and maintenance mode. In 1983, Madawaska reviewed its position and "... decided because of lack of markets and the coming on-stream of highgrade deposits in Western Canada and elsewhere, they should decommission their Bancroft properties" (Madawaska, 1983).

Madawaska ceased operation in the Bancroft area in 1982 and the facility is now being decommissioned. A cover of mine rip-rap has been spread over the tailings to allay dust. Revegetation is proceeding naturally. Since shutdown, the concentration of Radium-226 in seepage from No. 1 tailings area has decreased from 2.1 Bq/L in 1981 to 0.9 Bq/L in 1984, suggesting a flushing of original tailings pore water and a tendency toward stabilization.

2.2.2 Group II: Inactive Tailings Site from Mills that Used Strong (5%) Sulphuric Acid Leach

The Melis report (1984) lists the following inactive tailings areas in this category:

<u>Site</u>	<u>Date of Operations</u>	<u>Tonnage (Approximate) x 1,000 tonnes</u>	<u>Area of Tailings (Approximate) Hectares</u>
Nordic	1957 - 1968	11,000	100
Lacnor	1957 - 1960	2,700	24
Stanrock ¹	1958 - 1964	8,000	70
Spanish American ²	1958 - 1959	450	5
Pronto ³	1955 - 1966	2,100	46

¹ Includes 2,200,000 tonnes of Can-Met Tailings (1958 - 1960) plus neutralized bacterial leach solution produced from 1964 - 1969.

² These tailings drain into Denison's Long Lake Basin.

³ This property initially mined and milled uranium ore but changed over to a copper mine known as the Pater Mine.

These are all located in the Elliot Lake area. The first four are in the main camp. Pronto was some 18 miles south and initially milled a similar ore, changing over later to milling by flotation of a copper ore from the Pater copper orebody.

All these uranium ores are pebble conglomerates or reef-type ore. There are three common characteristics to these tailings:

1. Unlike the ores from the tailings in Group I, all of these ores contain pyrite, up to ten percent, usually varying with the uranium grade. Carbonates are virtually non-existent. The acid consumers are silicates and aluminates.
2. A major uranium mineral is brannerite. Thus, acid levels of five percent sulphuric acid at elevated temperatures are required to put the uranium into solution. These leach conditions leave little residual acid consumers to neutralize bacterially produced acid within the tailings.
3. The uranium grade of reef-type ore is low, averaging near 0.15% U.

The major environmental concern from this type of tailings is acid generation, from pyrite contained in the tailings from which the acid consumers have been removed by the strong acid leach process. The effect of bacterially mediated pyrite oxidation and the production of acidic seepage is well known. Because oxygen is necessary for the production of sulphuric acid, and because oxygen transport is via both diffusion and water percolating through the tailings, the most promising approach to the problem is to minimize both the diffusion of oxygen into the tailings and the percolation of water through the tailings pile. Three obvious methods are:

1. divert all runoff from the surrounding drainage basin around and/or past the tailings.
2. contour the tailings area to facilitate drainage and avoid leaving low areas where pools could form.
3. cover the tailings with a pyrite-free material which would increase the diffusion distance and, hence, reduce the flux of oxygen to the deeper tailings where pyrite oxidation would occur.

Mines with similar ores that are still operating have the advantage of planning their waste management system to meet today's regulations, whereas the inactive sites were built to specifications of earlier years and retrofitting to address the pyrite oxidation problem will be more expensive. Elliot Lake mines are, in general, decreasing in grade, and therefore contain a lower percentage of pyrite in the upper layers of the tailings areas. This would appear to offer some opportunity for reducing rates of acid generation.

2.2.3 Group III: Heap Leach

The third type of uranium milling process in Canada is the heap leach process. Only the Agnew Lake mill, located west of Sudbury, has used bacterial assisted, sulphuric acid heap leaching in Canada. This process is described in more detail in Section 2.3.

2.3 Present Decommissioning Practices

In Canada, there are currently two decommissioned uranium tailings sites at Beaverlodge and Agnew Lake. These are currently in the monitoring phase. One site, Madawaska, is in the final stages of decommissioning, while a fourth site, Rabbit Lake, is in the decommissioning planning stage.

Eldorado - Beaverlodge

The Beaverlodge mill was the only carbonate-leach uranium mill in Canada. It reached a rated capacity of 1,800 metric tonnes per day and, over the period of its operation from 1953, it produced approximately 2×10^7 kilograms of yellowcake from just over 10^7 tonnes of ore milled. This represented an average recovery of approximately 90 percent. Although it was a carbonate leach mill, a small acid circuit was added to extract the uranium from the small amount of sulphide mineralization present in the ore.

The ore contained a small amount of pyrite which would have consumed reagent in an alkaline leach circuit and was therefore removed by flotation. This low-grade pyrite concentrate was leached separately using a conventional sulphuric acid leach. The weight of this concentrate was about 3.2 percent of the ore. The acidic tailings were neutralized by adding them to the alkaline tailings, thereby using up some of the natural acid consumers. Prior to deposition, the large grain-size fraction was removed in the Dorrcclone plant and routed underground for use as backfill. Approximately 42.5 percent or 4.3 million tonnes of the mill tailings was separated for backfill.

The tailings management system was located to the south and east of the Fay shaft, and consisted of Fookes, Marie, Minewater and Meadow Lakes. Over the course of operation, tailings have also been deposited in Minewater Lake, Marie Lake and in the area of the Ace Creek floodplain. A total volume of approximately 10.1×10^6 tonnes of tailings were

produced over the life of the Beaverlodge operation, with the majority, approximately 5.5×10^6 tonnes, being placed in Fookes Lake. Approximately 50,000 tonnes of tailings were deposited in the Ace Creek area, 101,000 tonnes in Minewater Lake, and 170,000 tonnes in Marie Lake.

In the decommissioning of the tailings management areas at Beaverlodge, actions were taken to ensure the long-term stability and integrity of the tailings mass. This included a variety of:

- contouring activities to ensure surfaces blend in with the natural topography and thus eliminate the potential for catastrophic failure;
- removal of tailings from flood plain areas that may be scoured by flood waters;
- creating a rock/water cover, 0.6 m in thickness, over most of the tailings to minimize radon release and virtually eliminate dust losses; the building of saddle dams and blasting channels to divert drainage;
- covering of exposed tailings with waste rock to prevent erosion and attenuate gamma radiation;
- covering other tailings with borrow material; and
- placement of some tailings and sludge in abandoned raises and shafts.

Agnew Lake Uranium Mines

The second uranium mill tailings in Canada to complete the decommissioning stage is Agnew Lake Mines Limited. This mine was developed in 1968-69 with the intention of building a conventional mill. When uranium prices dropped in 1970, the operation was mothballed. In 1974, the company began on-site testing of a bacterially assisted, sulphuric acid heap leach process using the Eluex process to recover the uranium from the high iron solution. A full-scale plant was built in 1976 and went on-stream in June 1977. This system left the ore in stopes and hoisted only the 'swell' to surface, where it was placed on a leach pad. An acid solution containing indigenous Thiobacillus ferro-oxidans consumed the pyrite to produce both ferric iron and sulphuric acid. The solution was sprayed on the surface pile using heap leaching techniques and then was pumped up through the stopes under flood leaching conditions. The uranium was removed from the solution by ion exchange and the eluate treated by solvent extraction to produce a high-

grade yellowcake. The bleed from the system was neutralized with lime and the resulting sludge pumped to a valley south of the mine site. This valley contained a "saddle" between two drainage systems: Ministic Creek and John Creek. In 1968, when the company planned a conventional mill, it was decided to put the tailings on the west, or John Creek, side of the saddle and decant to the east, or Ministic, side. Using shaft rock, a mine rock clay-faced dam was constructed across the valley.

In 1976, this dam was redesigned to include a slurry wall and hypalon synthetic liner to further minimize seepage toward John Creek, a local trout stream. Two earth dams were built east of the saddle on the Ministic watershed. Both had control towers so that the discharge of the large reservoir could be polished, if necessary, before being discharged into Ministic Creek. The critical parameter in the effluent turned out to be ammonia from the blasting agent and Eluex system. In operation, the sludge was retained west of the saddle and the solution allowed to build up behind the first dam on the Ministic side. Because the solution was only complied with, the ammonia limits of the Ontario Ministry of the Environment during the spring runoff, the solution was stored behind the dam and discharged once a year.

The situation at Agnew Lake is unlike any other uranium mine. Their tailings were discharged as a sludge composed of gypsum and hydroxides of iron and thorium. This sludge is 99.5% minus 200 mesh, and has a moisture content of 83 percent. The unconsolidated nature of this sludge caused decommissioning concerns. The area of the tailings site is 30 ha (76 acres). The leached-ore pile was a source of concern, but it had been reduced to 0.0095% uranium and 0.2% sulphur. In decommissioning, the entire leach pile, as well as the PVC liner from the pad and layers of sand and rip rap between the pile and PVC liner, was mixed into the tailings sludge to help consolidate this and allow revegetation. The portion of the pad underlying the PVC liner was uncontaminated and, thus, decommissioning only entailed recontouring and revegetation.

The first decommissioning action was to decrease the downstream slope of the west dam by placing waste mine rock on the downstream side.

The problem of sludge stability was addressed by test work which showed that, if the leached ore were mixed with the sludge, a stable mass resulted which would support vegetation. The mixing entailed dumping the sludge on the leached ore and mixing with a dozer.

The runoff was sloped away from areas sensitive to erosion.

Madawaska Mines Limited

Madawaska Mines Limited is the successor company to Faraday Uranium Mines Limited, who built and operated a sulphuric acid leach plant in the Bancroft area from 1957 to 1964. Madawaska reopened the property in the 1970's and operated the mill from 1976 to 1982. The Madawaska facility currently is being decommissioned. The ore was in a pegmatite and the leach conditions were mild at ambient temperature and pH 1.8. These tailings were neutralized with lime.

Madawaska has two tailings areas. No. 1 area is adjacent to the mill, and No. 2 area, used in the period 1957 to 1962, is along Highway 28. No. 2 area contained a small pond known locally as Plunkett Lake which was fed and drained by Bentley Creek. Bentley Creek was diverted to the south by dams made from mine waste rock. These dams rise some 5 to 8 meters above the creek and serve as roads around the 10 hectares of tailings. After twenty-five years of existence, they appear stable.

Gravel from a small adjacent pit was used to cover the tailings of No. 2 site, to allay dust and to provide a base for native vegetation to encroach. Today, the natural vegetation for the area has successfully covered much of the site.

In 1983, the situation for decommissioning could be broken down into the following components:

1. Disposal of barium/radium sulphate precipitate in the settling pond and decommission the pond.
2. Placement of a heavy berm downstream of the east dam (No. 1 area).
3. Reconstruction of the drainage system from an area to the north of the No. 1 area, which, during operations, had been drained past the No. 1 area through a pipeline.
4. Covering of the tailings area with approximately 30 cm of borrow to allay dust, provide a base for revegetation and decrease gamma radiation.
5. Minimization of the seepage from the west side of No. 1 area. (During operations, this seepage was recycled to the mill.)

It had been proven that the local surficial materials had the ability to absorb cations like radium from solutions percolating through the soil. Madawaska's ore is low in pyrite or other sulphides and, therefore, is not acid generating.

Using these facts, Madawaska proceeded as follows:

1. In a dry, isolated section of the tailings area, at the upstream edge of the tailings, a pit, approximately 6 m in depth, was bulldozed. The barium/radium sludge was pumped from the settling pond to the pit and the pond cleaned out. The tailings pit was then backfilled after the solution had drained. Holes were drilled in the floor of the settling pond to prevent water from accumulating and the pond is being backfilled. To date, there have been no changes in the monitoring results.
2. A berm was designed for the east dam and was constructed out of mine waste rock. This berm was covered with pit run gravel and topsoil, allowing local vegetation to colonize it.
3. To deal with the spring run-off from the area to the north, it was decided the only reasonable approach was to construct a rip-rapped ditch across the dam and monitor the uptake of elements like radium-226. The information gained in the first year indicated the uptake was minimal. In 1984, it was decided to breach the west dam and eliminate the original tailings pond. This would have a further advantage of lowering the water table in the tailings and further stabilizing the whole mass. The water flowing through the breach responds to a gravel filter pond before percolating to the regional watercourse.
4. The waste rock used to build the tailings dam was some 2 m above the tailings surface at the time of closing. This rock was bulldozed onto the tailings surface to allay dust. The remaining surface was covered with gravel.
5. The seepage on the west side of No. 1 area has always been assumed to originate in the tailings pond, approximately 15 meters immediately above. This pond, during operation of the mill, contained solution with 75 to 100 Bq/L of Ra-226. After percolating through the tailings, the seepage was about 2.1 Bq/L (1981 average). In 1982, the average was 2 Bq/L. Despite a

decrease in hydraulic head, which has reduced the flow and thus dilution, the average radium-226 concentration was 1.5 Bq/L in 1983 and 0.86 Bq/L in 1984.

Monitoring will continue until 1988.

Eldorado - Rabbit Lake

A fourth tailings site to be decommissioned will be the Rabbit Lake tailings site, owned by Eldor Mines, Eldorado Resources Limited (and formerly operated by Gulf Minerals Canada Limited). This site is currently in the decommissioning planning stage. The open pit stopped production in 1984, but the mill continues to operate on stockpiled ore. The tailings area now in use will be decommissioned but, in this case, the activities will be carried out by an operating mine because Eldor Mines is developing the Collins Bay B-Zone and will mill B-Zone ore in the modified Rabbit Lake mill. B-Zone mill tailings will be deposited into the mined-out Rabbit Lake open pit.

The Rabbit Lake orebody was found in 1968, with mill construction initiated in 1972. The mill is a conventional sulphuric acid leaching plant, with solvent extraction used to recover the uranium from solution. The tailings area covers approximately 53.8 hectares (133 acres) and contains 5.87×10^6 tonnes of neutralized tailing. The owners are now evaluating a number of alternatives involving in-situ decommissioning of the present tailings.

2.4 Future Decommissioning Proposals

To estimate decommissioning costs for an operating mine, one must first define "decommissioning cost". In this report, "decommissioning cost" is any cost incurred, after the mine ceases operations, to ensure the tailings area will be environmentally acceptable at present and into the foreseeable future. Money spent to meet current operating regulations, even though this money may reduce future costs, is not included in decommissioning. This study does not address the costs of mine, mill and related support facilities prior to decommissioning. In Canada, the operating mines can be broadly divided into two groups.

A - Low Grade/Large Tonnage

The low grade/large tonnage operations are located in the Elliot lake area of Ontario. These mines all started in the 1950's and some have been operating for thirty years. These mines have contracts for uranium concentrate into the next century.

These mines have improved their waste management practices in line with increased regulatory attention in the uranium mining industry since their inception. Initially, tailings were contained behind dams made of mine waste or cycloned tailings. Today the mines must contain their tailings behind dams constructed to hydraulic dam specifications. This is an operating cost that may greatly reduce the final decommissioning cost.

These low-grade ores generate large volumes of tailings which, in the Elliot Lake area, have the potential to generate sulphuric acid seepage if oxygen is allowed to penetrate through the tailings. The estimating procedures outlined for Group II facilities will be of use in making preliminary estimates for decommissioning this type of tailings. The criteria should be used with care, however, when one considers the size of these tailing sites. One site is in excess of 240 hectares in size and six times the 40-ha site used as a model in this study. Probably as critical as the cost would be finding a source of cover within a reasonable hauling distance. Thirty centimetres of cover will require about a million cubic metres of material. There would almost certainly be significant environmental consequences of the extraction of this volume of cover in the Elliot Lake region of Ontario.

B - High Grade/Small Tonnage

This second group is characteristic of ores of northern Saskatchewan. The mines that process these ores date from the early 1970's and have the advantage of being developed under the more recent regulations of the AECB and provincial agencies. A number of additional ore bodies in the area may be developed in the near future.

Because of their high-grade ore and higher spread between product production and selling costs, these mines have financially been able to undertake projects investigating novel tailings management practices, such as layered tailings and in-pit disposal, which are

beyond the reach of smaller companies. The high-grade ore makes for smaller tailings areas although of a higher specific activity. In some cases, however, there is an abundance of cover material available locally.

Some companies are exploring the advantages of newer methods of tailings disposal which take advantage of local site conditions or new technologies, while at the same time minimizing the rate of loss of potential contaminants from the tailings. This is important because of the fact that the higher grade of ore will mean a higher source strength of uranium decay series radionuclides in the tailings mass itself.

SECTION 3

COSTS OF DECOMMISSIONING

3.0 COSTS OF DECOMMISSIONING

In order to assess the range of costs that may reasonably be expected to be incurred in decommissioning a uranium tailings management area in the Canadian environment, two approaches have been employed. The first is to consider a generic 40-ha reference site and apply unit costs to it. The second is to look at actual decommissioning costs for a site and compare it with unit costs.

3.1 Generic Unit Site Costs

A hypothetical inactive site of 40 ha was chosen to attempt a generic economic appraisal of the costs of decommissioning. Table 3.1 summarizes the costs calculated for a 40-ha site. Table 1 in Appendix 1 presents the assumptions used in cost calculations, while Tables 2 and 3 in Appendix 1 illustrate the calculations for test cases. The cost estimates were made using "Building Construction Cost Data 1982" published by Robert Snow Means Company Inc. (Means, 1982). The costs used are in Canadian funds escalated for three years at 7% inflation. No allowance has been included for the General Contractors mark-up which is usually 10%, but the costs do include overhead and profit for the sub-contractor. All unit costs are rounded off, for example, a 4-m high security fence set in concrete is listed at \$96 US per linear metre which, increased by 123% for inflation, becomes \$117 US. The Means (1982) factor for work done in Canada, and using Canadian funds, is 0.993 which, for simplicity, was rounded to 1, and thus \$117 Canadian.

The unit cost system of developing a cost budget for decommissioning and site abandonment must be used with care. The unit costs are considered valid for Edmonton, Alberta and Toronto, Ontario. Because Elliot Lake is an established mining camp, it is considered to be similar. Costs for isolated or remote mining sites will have to be factored up. Suggested factors are:

Bancroft Area	1.5
Beaverlodge	2 - 3
NWT	5 - 7

A range is given in some cases because of the uncertainties of mobilization, service and supply. The cost calculation spreadsheet (Appendix 1) allows for such a "remoteness factor".

TABLE 3.1: SUMMARY OF COSTS FOR HYPOTHETICAL 40-ha TAILINGS
DECOMMISSIONING AT SITE WITH REMOTENESS FACTORS OF 1
(TORONTO AREA) AND 1.5 (e.g., BANCROFT)

Cost Factor	Costs (1985 Cdn \$) FOB Toronto	Costs (1985 Cdn \$) at Remote Site
Security Fencing	\$2.62 E5	\$3.94 E5
Physical Stability	\$5.28 E5	\$7.96 E5
Diversion	\$1.34 E5	\$2.00 E5
Cover	\$1.56 E6	\$2.34 E6
TOTAL	\$2.48 E6	\$3.73 E6

Because of the short working season in some of the areas, extra care must be used in estimating manpower and equipment requirements.

In the generic example, the minimum circumference of a 40-ha site is calculated to be 2,240 m, and 30 cm of cover would require 122,613 cubic metres. Factors for specific sites are straightforward, and the actual perimeter and area of the tailings can be measured from topographic maps.

The following decommissioning activities are discussed both as to their needs and method of costing using unit prices.

3.1.1 Fencing

The use of fencing to prevent or discourage intrusion of a tailings site has been proposed in the past. To be effective, such a fence would have to be of security grade, which costs \$117/m.

The use of fencing is not without its negative aspects. A fence accentuates any perceived concerns associated with uranium tailings. To be effective, the fence itself would have to be patrolled and maintained in perpetuity. This cost has not been added to the estimate as it would be infinite. Fencing should only be for transitional phases of post-decommissioning monitoring where there is a real threat of intrusion and where more permanent alternatives to prevent intrusion, where necessary, are to be put in place.

3.1.2 Physical Stability of Dams and Dikes

The initial concern in any decommissioning is the actual stability of any existing dikes or dams. This usually results in decommissioning activities increasing the loading capacity of the dam if there is a concern about failure through overturning. The amount of new construction necessary will be site specific and the design will have to be approved by competent geotechnical personnel. The cost of new construction can be approximated by breaking the requirements into sub-activities.

Clear and Grub

The area below the berm or dike may have to be cleared, grubbed and chipped. The slash produced could be disposed by using it for cover on the tailings.

The cost of clearing and grubbing is estimated to be \$6,550 per hectare.

Ballast for Berms

The ballast used for this type of work is usually common borrow or waste mine rock, available locally if it is not pyritic or otherwise reactive. The ballast is covered with topsoil to encourage local vegetation to grow. This will also discourage erosion. These costs can be estimated by individual activities:

- | | |
|--|-------------|
| 1. Common borrow - obtaining, hauling less than 2 km, spreading but not compacting | \$7.50/cu m |
| 2. For longer hauls, add per km | .60/cu m |
| 3. If top soil is removed, stockpiled and replaced | 6.00/cu m |
| 4. Seeding - Hydraulic seeding with fertilizer and wood fibre for mulch | .80/sq m |

A decrease in the above costs may be available to operating mines decommissioning an inactive site because currently produced waste rock would be available and could be used, if suitable.

3.1.3 Diversion Ditches

Diversion ditches in the Canadian Shield will often be in rock. An average cost of drilling, blasting and excavating a ditch to carry headwater runoff in rock is estimated at \$71.00 per m³, for less than 1,500 m³ and \$62.00 per m³ for larger quantities. In planning the ditches, they should be large enough to absorb incidental debris and not require periodic cleaning.

In those areas where sands or gravels adjoin the tailings, slurry trenches may be required to either keep water from entering or leaving the tailings mass. A concrete wall to divert water is estimated at \$25.00 per cubic metre. An alternate method of estimating often used is \$290.00 per square metre of vertical face of the trench. If the trench is downstream, and requires bentonite to seal it and absorb cations such as radium, add \$17.75 per cubic metre. The remoteness factor used to scale costs associated with activities using concrete or bentonite may be considerably higher than the average factor because of the high costs of transportation.

3.1.4 Covers

Cover for the tailings can be the major decommissioning cost (Table 3.1). The cover sources, materials, types and volumes can cause great variations in this cost. Before a cover is laid, the site must be contoured to encourage precipitation to drain rather than form pools which would allow water to percolate into the tailings. Using a 200-HP dozer to grade tailing, assuming they are stable enough to support a dozer, will cost \$8,500 per month. The amount to be moved is site specific, but one month of equipment rental and labour is estimated.

A silty sand or soil cover 30 cm thick could reduce both average energy radiation and, in the case of pyritic tailings, reduce oxygen penetration (and thus acid generation) by an order of magnitude. Thirty centimetres of cover requires 122,613 m³ of borrow to cover a 40-ha site. A further 10 cm of topsoil is required for revegetation.

If one considers the U.S. Environmental Protection Agency suggested criteria to bring radiation and radon exhalation to average background, the depth of cover could be in some cases up to 10 m, depending upon ore grade and water content of the tailings. This thickness would likely be less in the moister Canadian climate. The volume of cover would be 3.6 million cubic metres. No money has been allowed to locate, environmentally assess, clear and rehabilitate the borrow site in this generic estimate.

Landscaping the cover is considered to be minimal and, in the most cost-effective approach, indigenous vegetation is relied upon to colonize the site. Hydraulic seeding, if necessary, would cost on the order of \$8,500 per ha.

Asphalt covers have been proposed for some applications in the U.S. because they are water tight and, therefore, should prevent water and oxygen from entering, and radon from leaving the pile. Asphalt covers require a sub-base of compacted crushed rock (which is nearly three times as expensive as common borrow) on which to lay the asphalt, at \$112,500 per hectare. The only successful application has been in South Africa where asphalt tops have been laid on uranium tailing piles to accommodate a drive-in theatre. No post-asphalt application monitoring data has been collected to our knowledge.

In the Canadian climate, frost can be very destructive to asphalt roads. Frost heaving on large surfaces would be expected to destroy the integrity of any asphalt cap, and it would be very costly to maintain. The high cost of installation plus the high cost of maintenance would likely eliminate the use of asphalt in Canada in all but small site-specific areas.

Appendix 1 presents details on cost estimations on both a per unit basis (Table 1) and with application to a hypothetical 40-ha site (Tables 2 and 3). When used with discretion on a site-specific basis, these estimated unit costs should give a budget-type estimate. The estimated unit costs do not include the General Contractors mark-up, and no allowance has been made for overtime which could be required on remote sites. Caution is advised in estimating manpower and equipment requirements for any site that would have to be serviced by barge or aircraft.

3.2 Decommissioning Costs in Literature

A large volume of literature is available on the technical and environmental aspects of uranium mill tailings. Very little of this provides usable cost information, since this is most often found in feasibility studies which are not public. A number of specific alternatives have been researched, such as moving tailings to alternate locations (U.S. Department of Energy, 1985), neutralizing barriers (Opitz and Sherwood, 1984), chemical stabilizers (Elmore and Hartley, 1983), effectiveness of alternative covers or removal of radioisotopes (Osborne, 1982), thermal stabilization (Dreesen *et al.*, 1983) and chemical treatment of leachates (Averill *et al.*, 1982). These are summarized by Sherwood and Serne (1983). Very few of these provide either a complete discussion of all decommissioning activities or the costs involved. Many of the techniques discussed are experimental and as yet unproven, and the costs associated with these activities are, at present, very speculative.

Several overall cost estimations were provided. Elmore and Hartley (1983) estimate tailings stabilization costs at \$680 to \$3,600 per hectare. MacLaren Engineers (1984) estimated \$300,000 to \$64,000,000 for decommissioning of the Rabbit Lake site, depending on the alternative approach taken. These emphasize the site-specific nature of tailings site decommissioning requirements, which is difficult to address in a generic study.

3.3 Canadian Decommissioning Costs

In Canada, several decommissioning projects have been undertaken and others proposed, and alternatives costed. In order to assess the practicality of applying generic assumptions to decommissioning, it is instructive to examine several 'real world' examples and compare them with a generic appraisal of a similar site.

3.3.1 Madawaska

The Madawaska mine, situated approximately six kilometres southwest of the town of Bancroft, Ontario on Highway 28, operated as a producing mine from 1957 to 1964. It was closed from 1964 to 1967, pumped out in 1967 and developed ore from 1967 to 1976, when the mill was reactivated and operated until July, 1982. The property is being decommissioned following cancellation of Madawaska's foreign sales contracts.

The initial tailings area, known as tailings area No. 2, was decommissioned in 1962 by spreading local borrow over the tailings. The local borrow plus the fact that the tailings are non-acid generating, has allowed indigenous vegetation to encroach and cover the area.

The experience acquired in over twenty years of operation was valuable in developing an overall decommissioning plan for tailings area No. 1, which included:

- building a berm downstream of the east dam to assure stabilization in the long term;
- excavating a pit in a dry area of the tailings, pumping the precipitated barium/radium sulphate from the settling pond into the pit, backfilling the pit and contouring the surface;

- covering the tailings with mine rock or local borrow; contouring the surface; this was done to allay dust, reduce radon exhalation and attenuate gamma radiation; and
- forming a channel across the tailings area to guide spring run-off over the tailings, and lining the channel with rip-rap.

Table 3.2 shows the breakdown of costs to perform the above work. Because Madawaska had mine rock available adjacent to the tailings area, and the mine crews and equipment were available, two sets of cost estimates are shown: first, the generic (Means, 1982) cost estimate for work performed by a contractor, and second, the company departmental estimate for labour and supplies. The actual cost is shown in the last column.

The difference in the estimates accentuates the problems of estimating the cost. The generic cost of work done by contractors must include mobilization and profit. The estimate by the Madawaska department does not include overhead and is carried out by staff familiar with the site and equipment available. The actual cost reflects the ability of the mine management to accomplish the task efficiently and to make the most of local situations. A case in point was the planting of 3,800 seedling pines using student labour for \$1,000. This would be impossible in a remote area.

No site factor has been used but the estimate indicates the factor for using mine staff and equipment would be 0.8, i.e., mobilization and contractor profit.

3.3.2 Agnew Lake Mines Limited

Agnew Lake Mine had a reef-type uranium ore and was located 50 kilometers west of Sudbury, Ontario. This property was unique in that the uranium was extracted using a bacterially assisted ferric leach on run of mine ore in stopes and on a surface heap. The surface heap consisted of development ore and "swell" from the stopes. The ferric uranium solution was treated by Eluex to recover a high-grade yellowcake.

The waste products consisted of the exhausted leach, precipitated gypsum and hydroxide sludge. The leach pile was supported on a layer of sand overlying an impervious liner. The sludge pond was contained in a valley behind an impervious dam.

TABLE 3.2: MADA WASKA TAILINGS DECOMMISSIONING

Activity	General Specifications	Generic Unit	No. Of Units	Projected		Actual Cost	Variance	
				Generic Cost (Based on Means, 1982)	Madawaska Projected Cost		Generic/ Actual	Madawaska Estimate/ Actual
1. Berm on Downstream Side of East Dam	mine rock and local borrow	\$7.50/m ³	3,000 m ³	22,500	18,500	15,000	+57%	+23%
2. Cover	15 to 30 cm of mine rock or borrow on contoured surface, includes ditch and rip rap	22,230/ha	13 ha	288,990	221,800	181,000	+60%	+23%
3. Burying Ba/Ra SO ₄ Precipitate	dig pit in dry tailing and backfill, pumping precipitate from settling pond	6.30/m ³	900 m ³	5,670	8,700	7,000	-19%	+24%
		\$50/h labour and pump	100 h	5,000	1,000	1,000	+400%	0
TOTAL				322,160	250,000	204,000	+60%	+23%

Agnew Lake is the non-conventional uranium mining and milling operation in Canada. The decommissioning plan accepted by the regulatory bodies included:

1. adding a wedge of waste rock to stabilize the "west dam";
2. loading and transporting the leach pile (2.5×10^6 tons) one mile, mixing it with gypsum sludge and grading the surface;
3. moving the sand layer and PVC liner to cover the area; and
4. placing a vegetative cover on top.

Much of the work was an extension of the typical leaching operations employed, and the heavy equipment required was in-place or could be secured on short notice from the local contractor. It is, therefore, difficult to compare operating techniques with estimating for a generic site that has been abandoned.

The mine staff, knowing local conditions, estimated the cost of implementing their plans as follows:

o Loading, hauling and placing rock	\$2,142,260.00
o Road make-up, mobilization, etc.	57,740.00
o PVC laying and trenching (used PVC from site)	62,000.00
o 6" topsoil, landscaping and seeding	212,000.00
o Clean-up operation	<u>30,000.00</u>
	\$2,504,000.00
Contingency 15%	<u>375,600.00</u>
 TOTAL	 \$2,879,600.00
 Actual Cost -	 \$2,744,864.00

This is \$134,736.00 or 4.7% below the departmental estimate. Comparing this to a generic estimate highlights the advantages of locale and economy (Table 3.3). The company's estimate was based on movement of 2.5×10^6 tons of crushed ore having a tonnage factor of 18.23 cu ft/ton, or 1.27×10^6 m³.

TABLE 3.3: AGNEW LAKE DECOMMISSIONING

Activity	General Specifications	Generic Unit Cost	No. Of Units	Projected Generic Cost (Based on Means, 1982)	Agnew Lake Projected Cost	Actual Cost	Variance Generic/Actual
Cover and Berm	gravel	\$5.93	1.27E6 (-30%)	\$5,270,000			
	contouring	\$8,500	1 mo	\$8,500	\$2,142,260	\$2,530,000	+ 108%
	compaction	\$47.50	40 ha	\$1,900			
Revegetation	seeding	\$8,500	40 ha	\$340,000	\$244,000	\$206,328	+ 39%

The nearest category in the table is bank run gravel at \$5.93 m³.

	<u>x\$10⁶</u>	<u>x\$10⁶</u>
Cost to move 1.27x10 ⁶ x 5.93	\$7.53	
Allowance for size - 30%	2.26	\$5.27
Actual company cost		<u>2.53</u>
Difference		\$2.74

This difference of \$2.74 x 10⁶, or 52%, is the result of not having to include overhead profit, royalty on gravel, etc., plus familiarity of the operation.

Comparison of the generic and actual costs of landscaping and establishing a vegetative cover is shown below:

o The total area landscaped approximated 40 ha.	
o Generic estimate was \$0.85/m ² or \$8,500/ha.	
o Estimated generic cost: 40 ha @ \$8,500/ha	\$340,000
o Actual cost	<u>206,328</u>
Variance	-\$133,672 = 39%

Again, the difference is overhead, profit and knowledge of locale.

3.3.3 Beaverlodge

The Beaverlodge Mine was operated by Eldorado Resources Limited, near Uranium City on the north shore of Lake Athabasca in northern Saskatchewan, from 1953 to 1982. A total volume of about 10 million tonnes of tailings were produced and disposed of in a series of local lakes.

Table 3.4 shows a simplistic breakdown of the decommissioning activities into the broad categories of tailings removal and redistribution and placement of cover. Removal of tailings from areas of spills was treated as the removal of common borrow and the \$5.70/yd³ cost converted to \$7.50/m³. The moving of tailings into the deep waters of Marie Lake also was treated as removal of common borrow at \$7.50/m³. The waste rock

TABLE 3.4: BEAVERLODGE TAILINGS DECOMMISSIONING ACTIVITIES

Activity	General Specification	Means Unit Costs (1985 Cdn\$)	Actual No. of Units ¹	Projected Means (1982) Cost	Eldorado Projected Cost ¹	Variance ²
1. Removal and Redistribution of Tailings						
	Removal of Ace Creek material and sludge to shafts	\$7.50/m ³	114,000 m ³	\$885,000	\$721,200	-\$163,800
	Meadow Lake Sludge	\$7.50/m ³	38,000 m ³	\$285,000	\$260,700	-\$24,300
	Move tailings to deep part of Marie Lake	\$7.50/m ³	65,000 m ³	\$487,500	\$530,000	+\$42,500
2. Placement of Cover						
	Cover Ace Creek catchments 2 and 3 and sewage - borrow	\$7.50/m ³	44,000 m ³	\$330,000	*\$300,000	-\$30,000
	Cover Fookes Lake delta waste rock/rip rap	\$7.50/m ³	63,000 m ³	\$472,500	\$367,700	-\$104,800
	Marie Lake delta - borrow(made on site)	\$7.50/m ³	23,500 m ³	\$176,250	\$186,700	+\$10,450
TOTAL				\$2,636,250	\$2,366,300	-11%

* The Ace Creek spills cleanup was arbitrarily split between removal and haulage and cover, total \$1,021,200.00.

+ The cover on Marie Lake delta and slurry to deep part of Marie Lake was split in proportion to m³ being moved out of a total of \$716,700.00.

1 Eldorado Resources Ltd (1983).

2 Actual costs were not available at time of writing. Variance is difference between costs estimated by the Means (1982) model used in this study and estimates by Eldorado (1983). Eldorado plans to issue a report on actual costs in the summer of 1986. Personal communication indicates these are close to those projected.

cover on the Fookes Lake delta was also treated as moving common borrow at \$7.50/m³, as the rock was already available. In practice, the rock cover was obtained by blasting rock adjacent to the tailings beach or beach on Fookes Lake, and spreading it over the exposed tailings. This approach was chosen because of the availability of drilling and blasting equipment on site. These materials would have had to be removed from the site at additional cost if not used, and thus this approach represented a decommissioning savings.

No site factor was added for the Beaverlodge tailings decommissioning as labour, equipment and support facilities were already at the site, being associated with the winding down of the mining operation. Table 3.4 shows that the unit cost estimates based principally upon short-distance haulage of common borrow worked relatively well for this situation, with the overall presented estimate being about 10% less than the generic estimate, and with the largest variance of about 30% associated with the placement of a waste rock cover on the Fookes Lake delta. This is very likely related to the difference between the estimated procedure and actual procedure used. Variances of this magnitude and typically possibly more could reasonably be expected based upon site-specific conditions.

The Eldorado projected costs shown on Table 3.4 did not include a charge rate for use of equipment as would be incurred if an outside contractor were used. The projected costs were based solely on labour, overhead, repairs, maintenance and fuel. Outside contracting estimates for the work were as high as \$4,700,000, or about twice as high as the internally projected costs. Exact decommissioning costs will not be available until later in 1986.

One cost not included was the \$750,000 spent in preparing the decommissioning plan.

Other causes for variance include the availability of experienced manpower and depreciated equipment due to the mine closure, the use of blasted local rock rather than hauling borrow to Marie and Fookes Lake and less sludge being moved than was estimated.

Where possible, comparisons seem within an order of magnitude or less. Unit prices appear similar. It must again be emphasized that remoteness, decommissioning

alternatives chosen, the availability of local materials (i.e., aggregates, sand, soil) and availability of local equipment and manpower (if a tailings area is decommissioned while the mining company still operates nearby, such as at Rabbit Lake) can affect costs significantly.

3.3.4 Rabbit Lake

The MacLaren Engineering (1984) cost estimates are summarized below (Table 3.5) for a middle-range (\$7,660,000) alternative to provide comparison to the model generated in our current study.

Several significant differences occur between the Mean's (1982) cost estimates used in this study and the estimates by MacLaren Engineering (1984) for Rabbit Lake. Although the overall cost variance is not great between the two estimates, the bases for these costs and estimates duplicated for individual components of the cost vary greatly. The cost estimations in our study do not include rehabilitation of tailings pipe, precipitation ponds or dams. These result in \$2,720,000, or 35.5% of the MacLaren cost estimate for Rabbit Lake. Our estimated cost for cover materials (sand 600 mm thick) is almost 5 times greater than in the MacLaren estimate. This presumably relates to a local, available source which is not at commercial prices. Our estimates for grading (1 month for \$8,500) are far under the MacLaren estimate. Both the time required and materials are likely underestimated or covered elsewhere in our estimate. Likewise, our haulage road costs probably are low for the quality of road in the MacLaren estimate.

3.3.5 Lakeview, Oregon

Neither actual nor estimated costs for decommissioning of uranium mill tailings sites are readily available in the published literature. Most such data are found in internal feasibility reports or company accounting files. The data in this report were largely made available through personal contacts or direct involvement of members of the project team. Determining costs of decommissioning programs outside of Canada was most difficult. The Lakeview, Oregon site was one exception in which very recent information was provided through personal contact with the U.S. Department of Energy. This provides a welcome comparison to the Canadian sites analyzed. It must be emphasized that the 16-km movement of tailings to a new site, and depth of cover

TABLE 3.5: RABBIT LAKE DECOMMISSIONING COST ESTIMATES (MACLAREN ENGINEERING, 1984)

Cost Parameter	Quantity	MacLaren Unit Cost Estimate	MacLaren Cost Estimate	Means (1982) Unit Cost	This Study Cost Estimate	Variance ¹
Excavate Drainage Ditches	87,500 m ³	\$ 2.64	\$ 230,000	\$3.15/m ³ ***	\$275,625	+20%
Construct Drainage	2,589 m	417.20	1,080,000	in above	-	-
Borrow Area	-	-	280,000	-	-	-
Haul Road	2,376 m	138.89	330,000	\$20,000/km	47,520	-86%
Grading	328,750 m ³	1.64	1,070,000	\$8,500	8,500	-92%
Tailings Pipe	-	-	40,000	-	-	-
Sand Cover (600 mm)	312,000 m ³	4.65	1,450,000	\$130,000/ha**	6,760,000	+366%
Topsoil (150 mm)	52 ha	9,615.00	500,000	\$6/cu m + \$8,500*	476,500	-5%
Treatment Pond Precipitate	171,000 m ³	5.21	890,000	-	-	-
Rehabilitate Dams	-	-	1,210,000	-	-	-
New Precipitation Pond	-	-	580,000	-	-	-
TOTAL			\$7,660,000		7,568,145	-1.2%

* est. 1 mo/40 ha

** est. as crushed stone

*** it is assumed by cost that this is not in rock

¹ Variance is difference between the estimate using this study's Means (1982) model and the MacLaren estimate. Actual costs were not available at the time of writing.

required for radon control, make this example quite different than those reviewed in Canada.

A comparison of cost estimates was made with the Lakeview Uranium Tailings Site in Oregon (U.S. Department of Energy, 1985). This site is located in a reasonably settled, ranching area with nearby sources of aggregate, soils and personnel, as well as easy access for vehicles. It would thus be considered to have a remoteness factor of 1 and no extra haulage costs for cover or stability materials. At the same time, the decommissioning must meet rather rigorous standards, such as depth of cover to contain radon, movement of tailings about 16 km to a more acceptable location and total rehabilitation and decontamination of the original site. Some of these must be factored out in any comparison with our cost model.

The overall cost of decommissioning this uranium mill and tailings site is estimated at U.S. \$12,250,000.00 to \$13,700,000.00, or approximately \$16 to 18 million Canadian. Since our model assumes that cheaper labour and materials compensate for the difference in dollar value, we will compare based on the U.S. dollar value. One must recognize this \$12 million cost relates to a mill which operated for only three years, producing only 155 tonnes of uranium oxide from 118,000 tonnes of ore. Even if uranium prices were \$90,000/tonne in 1958 (the time the mill was built), the total gross value would only be \$14 million. The site includes 12 ha of tailings, 10 ha of windblown material, 28 ha of evaporation ponds and 53 ha of other lands. The new tailings site is 16 km from the original site, and is proposed to cover 10 ha. Based on the four major cost categories in our model (Table 3.1 or Appendix 1), our comparison is presented in Table 3.6. In this comparison we have attempted to factor out costs related to movement of the tailings. The overall 33% difference in cost estimation could correspond to the US/Canadian dollar difference (in 1985).

3.4 Uncertainties and Assumptions

Based on the preceding comparison, the cost estimate generic model, using Means (1982) data, is a reasonable estimate of the upper range of costs that can be expected for uranium tailings decommissioning under current policies in Canada. At the actual mine site, costs should be lower if decommissioning is carried out, with access to operational infrastructures, due to:

TABLE 3.6: DECOMMISSIONING COSTS OF LAKEVIEW URANIUM TAILINGS (ONLY COSTS RELEVANT TO OUR MODEL INCLUDED)

Cost Factor	Means (1982) Cost/Unit	Units Lakeview	Means (1982) Cost Estimate	U.S. DOE Cost Estimate	Variance ¹
SECURITY					
- fencing, etc.	\$117/m	0	0	0	0
STABILITY					
- base materials	\$7.50/m ³	65,750	\$ 493,125		
equipment				\$2,170,000	
DIVERSION					
- excavation	\$62/m ³	11,468	\$ 711,016		
and equipment					
- clay liner-					
- labour	\$17.75/m ³	3,000	\$ 53,250		
- material	\$25.66/m ³	3,000	<u>\$ 76,980</u>		
- Subtotal			\$1,334,371	2,170,000	-39%
COVER					
- granular	\$7.50/m ³	356,257	\$2,672,000		
- rock	\$7.50/m ³	32,110	\$240,825	1,060,000	
- soils	\$1.68/m ³	13,761	\$ 23,120		
- labour/ equipment	\$10,000/mo	1 mo	<u>\$ 10,000</u>		
- Subtotal			<u>\$2,945,945</u>	<u>\$1,060,000</u>	+173%*
TOTAL COST			<u>\$4,280,316</u>	<u>\$3,230,000</u>	+33%

* Largely due to cover needed to stop radon exhalation.

¹ Variance represents the difference between estimates using the Means (1982) data from this study and the U.S. DOE estimate.

- availability of depreciated equipment and trained personnel at site on mine closure;
- planning of, and ongoing decommissioning activities, during operation;
- use of local resources, such as clean waste rock; and
- abilities of management to take advantage of local situations due to knowledge of the operation and local environment.

SECTION 4

MONITORING PRINCIPLES

4.0 MONITORING PRINCIPLES

In most cases, some form of monitoring may be needed for a long or indefinite period of time following decommissioning, in order to meet the objective of ensuring long-term protection to members of the public. Such monitoring requirements will depend on a number of site-specific factors, such as ore and waste-rock mineralogy, site location and characteristics of the environment and public at greatest risk relative to the site. These can be deduced, and thus the monitoring program best designed, based on pre-operational planning and operational monitoring programs. The monitoring program proposed and costed below is designed to meet requirements for a generic site. It, and the cost spreadsheet presented in Appendix 2, are thus meant to be all-inclusive. Site-specific cost estimates can best be made after deciding which aspects are not site-appropriate and then removing these from the spreadsheet matrix. This iterative process should occur throughout the monitoring program, with future monitoring requirements always based on a review of the most recent results.

Monitoring activities should be commenced during or before the beginning of mine/mill operation. This means, for example, that systems, such as a network of piezometers to monitor seepage from tailings into the groundwater, should be rationally designed and in place prior to decommissioning and may only require additions to the network to account for special decommissioning modifications. Such systems should be continued into the post-decommissioning monitoring program both for cost-efficiency and to provide an effective long-term data base against which any changes can be evaluated. It is assumed that such systems will be rationalized through both assessment of the site-specific potential for environmental contamination and compliance with all Federal/Provincial and local monitoring requirements.

4.1 Design of Monitoring Program

A rational environmental monitoring program should ideally be based on a site-specific pathway analysis. The major objectives of such an analysis are to:

- identify critical radionuclides, critical exposure pathways and population groups;

- identify important exposure pathways affecting potential long-term and regional impacts; and
- determine appropriate sampling media and locations.

Figure 4.1 shows a generalized environmental transfer pathway model. Major sources of environmental contamination from uranium mill tailings are:

- radon exhalation from the tailings management area;
- windblown tailings material; and
- leaching from tailings areas, especially acid leachate (from in-situ, pyrite-related acid generation) from inactive tailings into local surface or groundwater.

Human exposure pathways are:

Atmospheric and Terrestrial Pathways

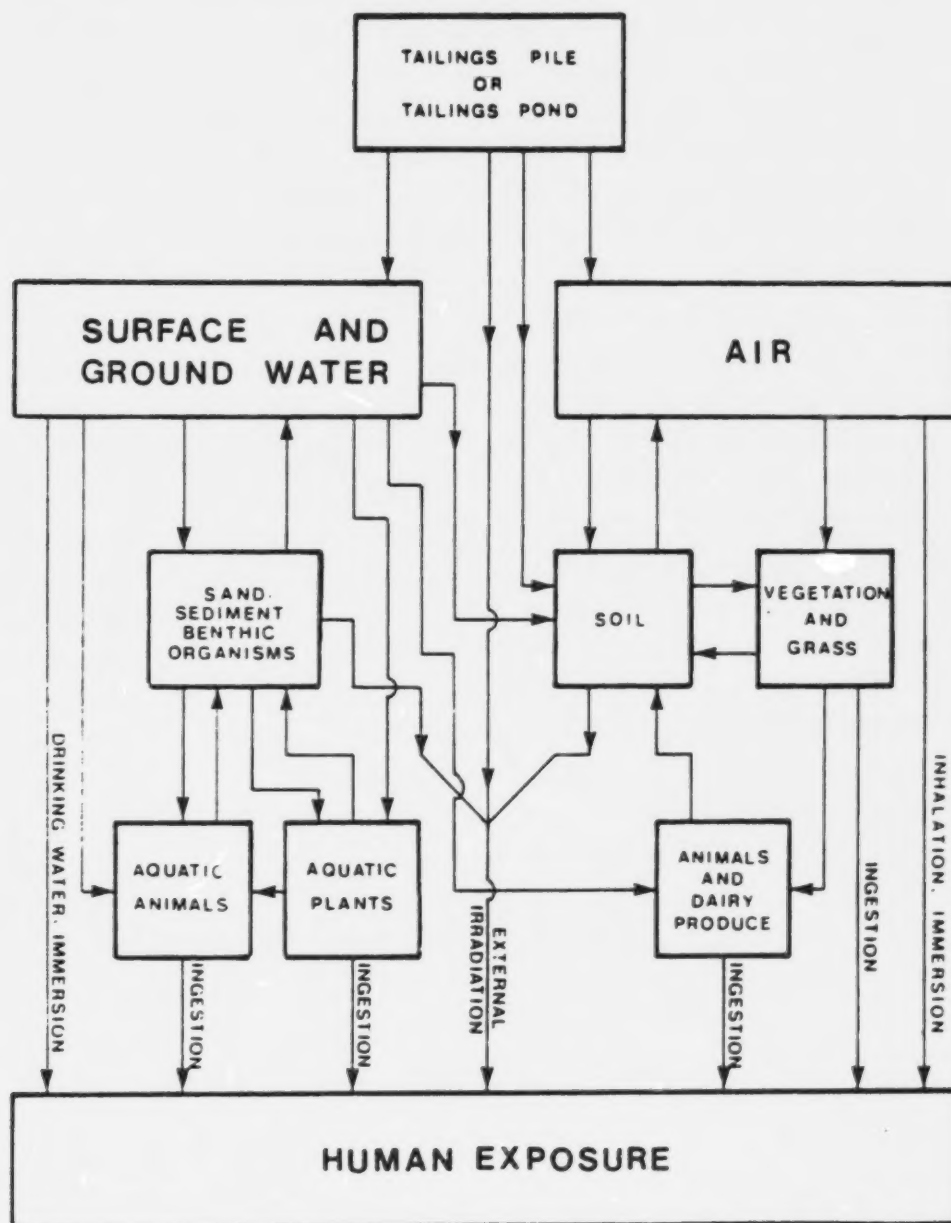
1. inhalation of radon and radon daughters
2. inhalation of airborne radioactive particulates
3. external irradiation
4. consumption of vegetation and food crops
5. consumption of meat and dairy produce

Aquatic Pathways

1. drinking water intake
2. ingestion of fish and other aquatic foods
3. domestic uses of water
4. recreation, such as swimming and boating
5. food crops irrigation with contaminated water
6. external irradiation from contaminated sediment
7. radon transport via ground water

ICRP 26 (para. 14) suggests that if man is adequately protected then other living things are also likely to be sufficiently protected.

FIGURE 4.1: ENVIRONMENTAL PATHWAYS IN URANIUM MINING LOCALITIES
(adapted from Environment Canada, 1978)



4.2 Tailings Variations

The monitoring program must reflect the current practice in tailings management at Canadian facilities. The following is summarized from Environment Canada (1978). In contrast to the practice in the United States, where uranium mines are generally located in arid or semi-arid regions and tailings are often stacked high on dry land, many Canadian mills operate in a wet environment, and the usual practice is to use natural depressions (which, in areas of low-permeability soils or bedrock and high water tables, usually contain water) for tailings disposal. AECB practice is to discourage the stacking of tailings above the height of the containment. Although tailings at operating mine/mill sites are usually wet, there are some dry beach areas in summer. Abandoned or non-operating tailings sites may also be relatively dry in summer. These constitute potential sources of suspended airborne particulate radioactivity.

Typical management of tailings liquid effluent at a Canadian mine/mill site is summarized in the following. Tailings are contained by dams or dikes, the overflow from which is treated with barium chloride to co-precipitate the radium. Flocculents may be added to improve settling. The effluent then passes through a settling pond or lake in which the radium precipitate or floc is allowed to settle. Further barium chloride addition may be made to the settling pond effluent to improve the removal of radioactivity. This passes through a second settling pond prior to discharge to waters available to the public.

Uranium mill tailings contain the radioactive decay products of uranium, a little residual uranium and Th-232, if present, and its decay products. Tailings usually contain two solid fractions, sand and slimes. The U.S. EPA estimates that the slimes are usually one-third of the total weight of tailings solids, but have about three-quarters of the total radioactivity. Since uranium and its daughters are in secular equilibrium in the ore, it is expected that the long-lived daughters such as Ra-226, Th-230, Pb-210 and Po-210 are present in approximately equal amounts in tailings. Canadian and U.S. data show significant concentration differences among different radionuclide species. Some variation is expected since chemical processes in the mill tend to segregate radionuclides between tailings size fractions to some extent. Also, the leach characteristics of radionuclides are different and may result in segregation. Because of segregation and differences in the physical transport of sands and slimes in the tailings pond, varying

levels of radioactivity are expected over the surface of tailings, and it is difficult to obtain a representative sample.

4.3 Airborne Releases from Tailings

Radon

The exhalation rate of radon from tailings is primarily dependent on the radium concentration, but is strongly influenced by the moisture content, the particle size and texture (sands or slimes) of tailings, temperature, pressure, atmospheric stability and weather conditions. Snow cover, rainfall and weather conditions may change the exhalation rate by a factor of 10 or more through an alteration of the diffusion coefficient. Calculations have shown that complete saturation of dry tailings with water may reduce its radon emissions by a factor of about 25.

Particulates

The problem of tailings resuspension by wind erosion exists with dry, open tailings areas. It is particularly significant during summer and fall when dry beach areas exist, and during gusty wind conditions. The release of particulate material is difficult to quantify. It depends on the water content of the tailings material, the particle size distribution within the tailings and wind velocity. Maximum winds and gustiness are more important than average wind velocity. Tailings stabilization, such as revegetation, is expected to significantly reduce the problem of wind erosion.

Aqueous Releases

Liquid effluent discharges, from non-operating tailings management areas, are generally smaller than those at operating tailings sites. However, passive or low-maintenance effluent treatment at non-operating tailings sites may not be as effectively carried out as at operating tailings sites.

Seepage of tailings water may occur through the retaining dam or downwards into the underlying ground. Seepage flow through a well-designed and constructed retention dam is generally small, typically less than 1 L/s, and is unlikely to be a major source of

concern, except at non-operating tailings sites where the integrity of the retaining dam may be suspect and receiving water dilution or receiving environment attenuation capacity may be low.

Underground seepage from tailings ponds may be significant if the underlying soil or rock structure is highly permeable and connected to shallow aquifers in the vicinity. There is a general lack of Canadian data on seepage rates below decommissioned tailings sites, although it is known to occur at least at one site (Madawaska Mine, at Bancroft) where groundwater seepage is employed as a means of disposal for barium chloride-treated effluent through attenuation. During operation, a pond in the central tailings area was used for recycle water. Excess effluent was discharged, after treatment with barium chloride, through a natural gravel filter. On decommissioning, the barium/radium sludge was buried in the tailings. Monitoring of leachates has indicated no contamination problem. A U.S. site where underground seepage had been studied in some detail is in the Grant's Mineral Belt at New Mexico. This study indicates that, because of the particular geologic structure of the area, about 50 - 70% of tailings pond water is 'lost' through seepage into the ground.

In areas such as Elliot Lake, where the tailings pyrite content is relatively high, the tailings may become more and more acidic as pyrite, near the surface of the tailings that is exposed to oxygen, oxidizes. This is a potential source of concern, especially at non-operating or abandoned tailings facilities since, as the pH is lowered, leaching of radionuclides and trace metals from tailings may be enhanced. Potential re-dissolution of radionuclides removed as a BaSO_4 -precipitate sludge may also occur if these sludges are exposed to acidic leach water.

SECTION 5

POST-DECOMMISSIONING MONITORING



5.0 POST-DECOMMISSIONING MONITORING

Following decommissioning, the mining company will likely cease to have a permanent presence at the site. For this reason, it is essential that a post-decommissioning monitoring program be designed, costed and the responsibilities for monitoring agreed to prior to mine closure. Since many such mines are in remote areas, the logistics of monitoring can become very significant, especially if no service industries are located in the area. In the Beaverlodge area, monitoring for the first five years is a shared responsibility between the company and the province. Following this 'demonstration' period, long-term responsibility for monitoring will become a provincial government responsibility.

Post-decommissioning monitoring programs have several main objectives:

- to assess the adequacy of rehabilitation methods, such as tailings revegetation;
- to ensure environmental contamination does not exceed regulatory standards;
- to identify and resolve any potential health or safety hazards; and
- to reassure the public that the decommissioned tailings area does not represent a liability to present and future generations.

Based on the above objectives, categories of monitoring are defined and cost estimates generated for each. These are:

- **Rehabilitation Monitoring:** to assess effectiveness of tailings containment, erosion control and revegetation;
- **Aquatic Monitoring:** to investigate potential long-term contamination by leachates;
- **Atmospheric Monitoring:** to investigate impacts from radon exhalation and/or wind erosion of tailings; and
- **Biotic Monitoring:** to evaluate possibility of increased levels in food chain due to release from aquatic or atmospheric pathways.

5.1 Rehabilitation Monitoring

Due to the logistics of conducting ground surveys in remote areas, especially in the absence of an existing base community or camp, the monitoring of tailings rehabilitation/stabilization success is, in such cases, proposed to rely heavily on airphoto analysis. Ground-level surveys are proposed on a less frequent basis to back up the airphoto interpretation. Of course, in more easily accessible areas, photogrammetric costs would outweigh those of ground survey techniques. Ground surveys give more accurate and detailed information, and are a necessity for contaminant monitoring in any case. Thus, at such sites, more frequent ground-level monitoring, supplemented by periodic overflights to assess large-scale events, would be recommended. Depending upon site logistics, these tasks may be logically combined. The spreadsheets developed in this study allow the site-specific flexibility to modify the cost estimates appropriately.

5.1.1 Aerial Photography and Interpretation

Table 5.1 and Figure 5.1 summarize specific activities and costs associated with airphoto analysis of decommissioned uranium mill tailings sites. Figure 5.2 breaks these costs down for the initial 5-year period. Appendix 2 provides the detailed cost estimates on specific activities. Large-scale aerial photographs are recommended at scales from 1:1200 to 1:5000. Flight sessions are assumed to take place three times in the first five years, twice in the next five years, and then at four-year intervals. As a result, the five sessions that should take place in the first ten years should provide an adequate base to quantify measure of change of site conditions. Furthermore, this record should assist field inspectors and update topographical maps.

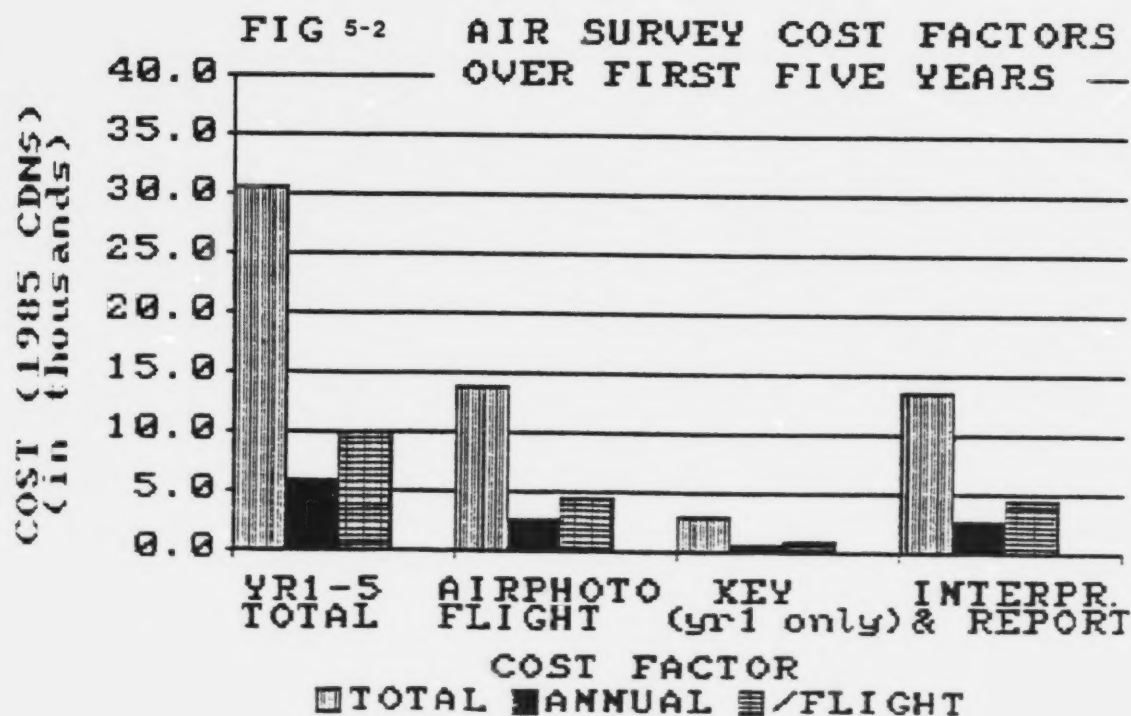
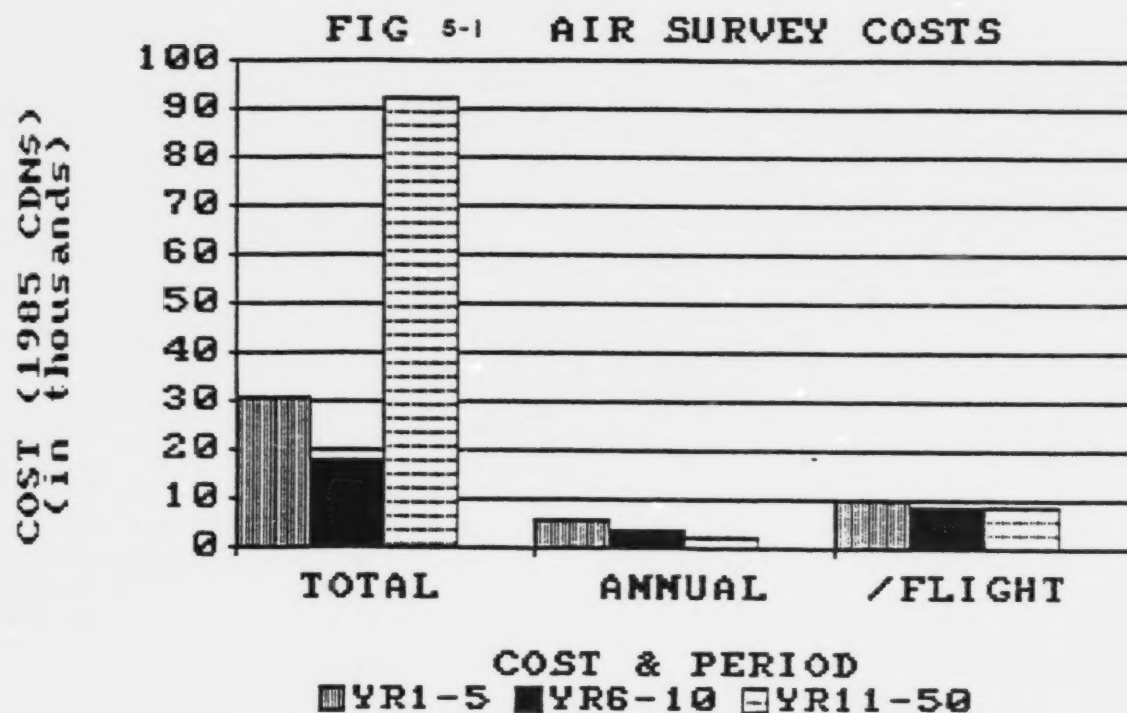
The need for monitoring should diminish over time, therefore, a reduction of frequency after the initial ten years is recommended. It is also recommended that at least one of the flights in the first five years be during the spring period, just after runoff and just prior to leaf-out, to assess recent erosion, and at least one during a mid-summer period to assess revegetative success.

a) Costs

Costs associated with the photographic flight sessions represent 63% of the total costs in the first five years and 74% in subsequent years. At \$500 per hour for flight time, the

TABLE 5.1: SUMMARY OF AERIAL RECONNAISSANCE AND AIRPHOTO
INTERPRETATION COSTS (CDN \$1985)

Cost Factor	Aerial Photography	Airphoto Key	Airphoto Interpretation and Report
FREQUENCY OF SURVEY			
● years 1-5	3	1	3
● years 6-10	2	0	2
● years 11-50	10	0	10
Cost per Time	\$4,625	\$3,200	\$4,600
COST/PERIOD			
● years 1-5			
- total	\$30,875		
- per year	6,175		
- per flight	10,292		
● years 6-10			
- total	18,450		
- per year	3,690		
- per flight	9,225		
● years 11-50			
- total	92,250		
- per year	2,306		
- per flight	9,225		



distance of the mill tailings site from the nearest airport will determine the extent of flight costs. This hourly rate (\$500) was determined through consultation with Toronto-based remote sensing companies: It represents a twin-engined plane plus equipment and manpower required.

A one-time cost of \$3,200.00 has been assigned for the first year of monitoring. This is to develop "keys" for each site in order to facilitate interpretation of future aerial photography sessions. Field work associated with development of keys (markers to identify features) is included in the first year of ground surveillance costs in Table 5.1. Eighty hours of professional time at \$40.00 per hour has been estimated as the cost of developing "keys". This represents a typical standard billing rate for a bachelor degree-level airphoto interpreter. Specific keys to be identified, and their associated time allotment, are indicated in Appendix 1. Time allotments are proportional to the level of difficulty, sophistication and volume of features to be identified.

Interpretation of aerial photographs also assumes a \$40.00 per hour standard billing rate. However, less interpretation time is anticipated because development of "keys" makes interpretation standardized for subsequent sessions. One week (\$1,600.00) of professional time has been allotted for interpretation. This is significantly less than the airphoto flight at \$6,225.00 (excluding key development). All features identified in Appendix 2, Table 1 will be interpreted for each session. If several tailings management areas can be flown in one flight (e.g., Elliot Lake area or Beaverlodge area), the cost per tailings area would drop substantially.

b) Identification and Interpretation of Features

Appendix 2, Table 1 lists the various features that will be aerially surveyed at a typical uranium mill tailings site. Actual time and effort required for each feature will vary from site to site. Professional time required is in proportion to the anticipated level of difficulty. These features and rationale are described in the following sections.

Erosion

This includes gully, sheet and wind erosion (blow outs). Precipitation and wind are dynamic modifying processes. Gullying is one of the most serious forms of soil erosion

where narrow, steep-sided channels are created. Sheet erosion is the removal of surface soils in a more or less even manner. Blow outs are depressions created by wind erosion. All of the erosion features can increase radon release and leaching of radionuclides into groundwater, therefore, frequent monitoring is required to identify these processes and allow the planning of remedial actions, where necessary.

Piping

Gully erosion piping is the result of water seepage through the gullies into horizontal tunnels that can result in geotechnical instability and the potential for increased radionuclide and trace element release. These can be difficult to monitor remotely, but airphoto interpretation can identify signs of problems and flag them for emphasis during ground-level surveys.

Flooding and Other Natural Disasters

Flooding causes dramatic erosion and vegetation loss, leaching and possible spreading of radionuclides to areas adjacent to the tailings site. Evidence of flooding, tornados, hurricanes and earthquakes may warrant a contingency on-site inspection and remedial action.

Cover Shrinkage and Damage

The integrity of the cover must be monitored to minimize radioactive releases into the ecosystem. Chemical attack (i.e., acidic precipitation) and weathering are difficult to examine through aerial photography. Cracks and shrinkage are relatively easy to identify by air photo analysis.

Differential Settling

Soil, vegetative and riprap covers may settle at different rates and create fluctuations in cover depth. This can compromise the shielding ability of the cover or increase erosionable surface area. Airphoto surveys can identify the occurrence of differential settling, but site surveys may be required to determine the extent.

Slope Failure

Slope failure involves mass movement of soil and material due to landslides, falls, avalanches, slumps and earth flows. These failures create instability in the mill tailings site. Vulnerable locations should be monitored with reference to previous records and topographic maps. Such events are usually significant enough to be easily identified through air photo interpretation.

Diversion Channels

Runoff is diverted from the tailings site through the building of engineered channels. Obstruction, damage and overflowing of channels will be monitored to protect the tailings areas from possible erosion. Diversion channels should be constructed in such a manner as to discourage beaver activity. The occurrence of such events can be identified by air photo analysis, but the determination of their significance might require seasonal field surveys.

Stream Migration

Streams have a natural tendency to migrate at various rates, depending on topography, rate of flow, slope, parent material and climatic conditions. Direction and flow rate of off-site streams will have to be monitored to prevent intrusion into the tailings area. On-site streams will be monitored for cutting, expansion and possible slope failure. If the stream has been modified through the use of dikes, levees and linings to minimize migration, these engineered features can be monitored through aerial photography.

Flora, Trees and Shrubs

Species of trees and shrubs should be identified and rate of growth monitored (canopy). If photographic scale is large enough, smaller species of flowering plants may be identified; however, it is probable that on-site field inspection will be needed to identify these.

Positive effects of flora intrusion include reduction in erosion and increases in soil stability and shielding factors. Negative effects include root penetration into the

tailings and subsequent radon release, although this is not likely to be of concern in the Canadian context. Radionuclides may enter into the food chain as a result of root penetration. If contaminants from the tailings are having a negative effect on vegetation this should be evident from an analysis of the summer colour photographs.

Animal Burrowing

Animal burrowing may weaken tailings covers, increase erosion, transport tailings to the surface and increase radon release. Although species are not likely to be identified through airphoto interpretation, location of burrows will assist field crews in trapping and identification of burrowing fauna and allow an evaluation as to whether or not the 'intrusion' is significant enough to warrant remedial action.

Revegetation

Tailings sites may be revegetated to reduce erosion and increase shielding factors. Success and failure of the flora cover should be easily identified through airphoto interpretation (especially infrared imagery). Evidence of succession and overall vegetative 'health' should also be examined, and implications to site integrity analyzed.

Riprap

Weathering of riprap is a slow process. However, it should be included in long-term monitoring to document any changes in the stability of the riprap.

Water Table

Fluctuations in the water table will be monitored by air photo interpretation through its effect on local water bodies, streams and vegetation. If changes are identified that result in the potential for increased erosion, remedial action may be necessary. Again, ground-level studies would be required to determine the significance of such changes.

Human Intrusion

Humans entering the tailings site may cause damage to fences, signs, engineered and natural features. This may involve hiking or hunting activities, or the intrusion of

recreational vehicles, such as moto-cross bikes, snowmobiles and other off-road vehicles. These vehicles may potentially cause severe damage to soil and vegetation cover stability. Ingestion of plants or animals by humans on the site may result in the input of radionuclides into the human food chain. Trails, tire tracks and litter may be evidence of human intrusion. At the same time, airphoto analysis will identify any land use changes in the immediate vicinity of the tailing site which might increase the potential for human intrusion.

Soils

Monitoring of soils will be essential for the successful growth of vegetative cover and reduction of erosion. Drainage patterns and soil-forming processes can be indicators of cover stability. Colour photography and multispectral scanner imagery has made soil surveys possible from aerial photography rather than through field work, the traditional method of soil delineation.

5.1.2 Ground-Level Surveillance

Ground-level surveys will serve to complement the assessment of the stability of decommissioned uranium mill tailings from sensing methods. These field investigations will ensure the effective monitoring of ecological and geological processes not readily identified by airphoto interpretation. Since costs for airphoto sessions are less than those anticipated for on-ground surveillance, a combination of both methods results in maximizing cost-effectiveness. Surface features such as groundwater, weathering, root penetration, settlement, chemical attack and cover shrinkage may, in some instances, be detected with greater ease through field inspection (UMTRAP, 1984).

Phase I inspections are regularly scheduled in the long-term monitoring of tailings sites. However, problems identified from aerial photography, previous on-site inspections, analysis of samples or reports from concerned individuals, may prompt a contingency inspection not scheduled in the long-term monitoring plan.

On-ground surveillance should take place during the early spring, just after surface runoff and just prior to leaf out.

a) **Frequency:** Frequencies discussed assume that the site has been adequately decommissioned to meet current regulatory requirements. Currently, in Canada, the mining companies are undertaking more frequent monitoring in order to demonstrate the effectiveness of decommissioning activities. During the first five years of monitoring, field investigations should be undertaken annually. Seasonal sampling on a quarterly basis is proposed for the first year. This will include both collection of environmental samples for laboratory analyses and a general site inspection to monitor for stability of decommissioning methods. Instruments set up the initial year will be read, recorded and dismantled in subsequent years. Markers will be set up for creating "keys" on the first field trip. These "keys" will be for identification of aerial photography features (Years 3, 4 and 5). The second 5-year period of ground-level monitoring is proposed on a bi-annual (every 2 years) basis (year 7 and 9). Thereafter, ground surveys are recommended on a 5-year basis. This monitoring protocol must be flexible, depending on the concurrent survey results. Any time that results indicate a significant increase in contaminant escape or cover instability, the monitoring schedule should revert to year 1.

Table 5.2 and Figure 5.3 summarize the ground-level monitoring program and costs. Appendix 2, Table 2 indicates specific activities and sampling to be conducted on-site. Processes that are less dynamic have less frequency of surveillance. These include weathering, geomorphic processes, monuments, markers, access roads and natural sites. These are not expected to change significantly from year to year. More dynamic processes, such as erosion, human and animal activity, and less stable features, such as fences and signs, are to be checked on each field trip. Materials to be sampled also vary with frequency. Radon, gamma, tailings and flora need not be sampled as often due to a slower process of change.

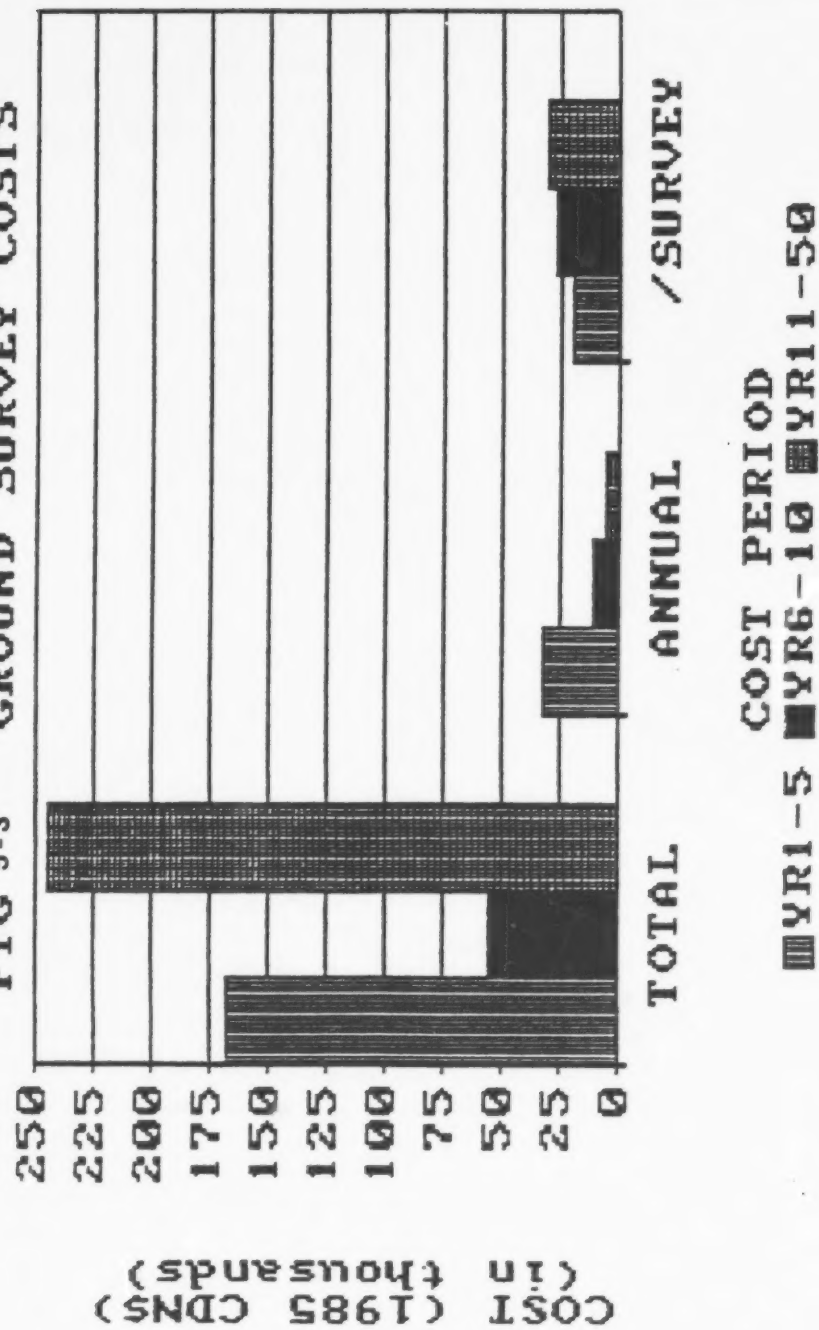
b) **Costs**

On-ground surveillance costs are summarized in Table 5.2. Details are provided in Appendix 2. Professional time is calculated at \$50.00 per hour. This is based on average typical standard billing rates for a 2-man crew (at \$60.00 and \$40.00 per hour respectively). Expenses for flight assume a remote location for the mill tailings site and include shuttle service from the major airport to the site. Lodging is estimated at \$65.00 per person per night for nine nights, and meals at \$25.00 per person per day for nine days. Total costs for flight, meals and lodging represent 18% of the total cost of the site

TABLE 5.2: SUMMARY OF GROUND-LEVEL MONITORING ACTIVITIES AND COSTS (SEE APPENDIX 2 FOR DETAILS)

Cost Factor	Costs in 1985 CDN \$					
	Years 1-5		Years 6-10		Years 11-50	
	Total	Per Year	Total	Per Year	Total	Per Year
Travel/ Accommodation	35,360	7,072	8,840	1,768	35,360	884
Tailings Integrity	9,100	1,820	6,000	1,200	20,800	520
Field Monitoring	1,920	384	2,360	472	7,680	192
Lab Samples and Analysis	108,475	21,695	32,950	6,590	157,120	3,928
Reporting	14,500	2,900	5,800	1,160	24,060	602
TOTAL	169,355	33,871	55,950	11,190	245,020	6,126

FIG 5-3 GROUND SURVEY COSTS



inspection. These could be significantly lower if the remoteness of the site results in the survey crew camping out.

As a result, cost for on-site inspection will vary slightly with the location of the tailings area in respect to the operational base of the prospective field crew, but professional time and laboratory analysis of samples will play a more significant role in total cost of on-ground surveillance. Laboratory costs are assessed at current (1985) rates charged by Beak Analytical Services. No reduction is applied for volume (one can usually assume reductions if over 10 samples are analyzed at one time). However, shipping charges and other related incidentals will probably make up for any differences.

The Eldorado estimate for annual monitoring costs during the first 5 years following decommissioning are on the order of \$24,000/a. These costs are similar to the estimate of \$33,871/a for the generic site but are based upon completely different sampling frequency and set of parameters to be evaluated. This emphasizes the need for careful site specific evaluation of monitoring needs.

Some of the features being monitored are less likely to change on an annual basis. Therefore, less dynamic features have a reduced frequency of inspection in order to maximize cost-effectiveness.

c) Ground Survey Activities

Signs and Fencing

A walking traverse of any fences present should be made, and breaks or damage recorded. Evidence of disturbance by humans should be noted. Problem areas identified by aerial photographs should be assessed in detail to determine the significance and possible causes of damage. Conditions of signs on the fence will be noted. Integrity of the fence and signs where a clear need has been demonstrated to minimize human intrusion, should be maintained. The frequency of such inspections should vary with the likelihood of disturbance. In remote areas, twice in the first 5 years should be adequate.

Surface Erosion

Erosion, settlement, sliding and creep of soils and parent materials will be noted by the field crew during surveys of the tailings management area.

Diversion Channels

Diversion channels and any associated riprap, sideslopes and concrete spillways will be examined for damage and erosion.

Human Activity

Evidence of human intrusion from airphoto analysis should be followed up by field crews. These intrusions include recreational vehicle track marks and hiking trails. Furthermore, field crews can look for mechanical removal of soils and trees, and evidence of litter. Contacts should be made with those responsible for any encroaching land-use changes to determine future plans.

Boundary markers, site markers, and survey monuments will be inspected. Any signs of human abuse or change in elevation or stability will be noted.

Animal Activity

Animal trails and burrows should be examined and photographed. Feces can be a good indication of species identification if sighting or trapping is not possible.

Signs of intrusion from local livestock that may have wandered into the tailings site should be noted. Grazing livestock may introduce radionuclides into the human food chain.

Flora

Tree, shrubs and ground flora which are re-invading or were planted on the tailings should be noted, and species identified and general conditions noted.

Covers

Covers will be examined for signs of deterioration, breaks, shrinkage, etc. The type of material used for the cover will determine the type of damage field inspectors should look for.

Weathering

Rock covers will be subject to weathering from physical and chemical processes. Although these processes will take place at a slow rate, long-term monitoring should predict the long-range durability of rock covers, riprap and other features. Changes in colour and lustre, oxidation, rounding of edges and cleavage may be evidence of weathering (depending on mineral composition). Inspections every 5 years for the first decade, and every 20 years thereafter, should be adequate.

Geomorphic Processes

Although these processes are usually very slow, long-range monitoring will ensure the integrity of the tailings site. Evidence of faulting, folds, strikes, dips, mass movement and extreme events (i.e., volcanoes) in the geographic area should be monitored carefully. Types of geomorphic processes will be associated with the regional topography and major climatic conditions. Naturally formed physical and geochemical anomalies on-site and in the adjacent areas will be inspected and changes noted. The anomalies could include such features as fresh heaves, salt boils and salt crusts. These will be monitored in a similar manner to that proposed for weathering.

Access Roads

It is assumed that, once a tailings area is decommissioned, access roads will be allowed to deteriorate. This process should be monitored by field crews to ensure erosion or runoff diversion does not threaten the integrity of the site. Any signs of human use should be noticed and new barriers created, if required.

d) Geological Sampling

Shear Testing

Shear strength testing is important in determining the stability and settling of uranium tailings. This can be accomplished in situ using various methods, such as the standard penetration test, cone penetrometer and vane shear test. This type of testing may only be required once following decommissioning to verify predicted behaviour after about 10 years, where conditions warrant.

Nuclear Density and Moisture

Testing for nuclear density of tailings material is also important for monitoring the stability of the tailings site. Nuclear density probes, standard penetration tests and cone penetrometers can be used to measure density. Nuclear moisture probes can measure water content of tailings material. This and the shear testing are proposed once after ten years, and, after that, only if the rate of stabilization is not satisfactory.

Surface Soil

Samples of soil at the surface of the tailings and at depth should be taken and major anions, cations, metals and radionuclides tested in the laboratory, as in Section 4.2.1. Nutrient content in soil samples may also be determined to assess the need for soil fertilization if plant growth is not comparable to that in the surrounding area. Analytical programs for soils and biota are proposed once in the first five years, and once every ten years after that, unless a problem is noticed and remedial action undertaken.

Tailings

Samples of tailings should be obtained from decommissioned sites. Parameters to be measured include grain size, water content, density and shear strength. Samples should be taken from areas that differ in characteristics such as grain size and moisture content. The number of samples will, therefore, be determined by the homogeneity and size of the tailings site. One sampling after every five years, and sampling every ten years after that, is felt to be adequate, unless remedial action is required.

5.2 Aquatic Monitoring

Both surficial and groundwater monitoring may be required to identify any contamination from tailings runoff or leachates. Monitoring sites should be determined as part of a pre-decommissioning (or if possible, pre-developmental) environmental assessment. They should include all localities with a high potential for contamination, all localities connected to human uses, as well as control sites.

5.2.1 Surface Water Quality

Both in-situ and laboratory analyses are proposed. The in-situ testing is important because it minimizes the potential for changes in sample character during transportation to the laboratory and serves as a quality control check against sample deterioration in transport. The lab analyses cover a greater diversity of parameters with a greater degree of accuracy. The following analyses are recommended:

In Situ:

- pH,
- conductivity,
- temperature, and
- dissolved oxygen

Laboratory:

- total dissolved solids,
- total suspended solids,
- acidity,
- alkalinity,
- radionuclides (uranium, thorium-230, thorium-232, radium-228, radium-226, lead-210),
- metals (iron, aluminum, arsenic, cadmium, copper, cobalt, lead, mercury, nickel and zinc), and other trace metals that may have been identified at levels which could result in a potential environmental concern, and
- major ions (calcium, magnesium, sodium, potassium, chloride, sulphate, nitrate and ammonia).

5.2.2 Groundwater Quality

At many decommissioned uranium tailings sites, groundwater contamination offers a potential for future concern. Assuming cover, revegetation and diking integrity, air contamination should be very localized and surface water contamination should occur primarily as a result of groundwater discharge.

Groundwater movement is very site-specific. The monitoring program must be designed to fit the tailings area. Monitoring and modelling of groundwater movements should have been a prerequisite to tailings site selection and management design. The post-decommissioning monitoring program should be based on these earlier studies. Cost estimates assume that installation of the piezometer network has occurred during the planning or operational stages.

Figure 5.4 illustrates a conceptual tailings site groundwater monitoring network. This was used to predict costs. It must be emphasized that the number, depth and location of monitoring wells will vary from site to site. In this approach, there are three levels of monitoring. Wells will be concentrated in the hydrogeological down-gradient direction.

The first level of monitoring, with wells under the tailings and in the immediate periphery of the tailings site, will be for all parameters outlined in Section 5.2.1 above. The second level of monitoring will be for major ions as an indication of the leading edge of the plume. As soon as these levels rise, the sampling station reverts to first-level analysis. The third level requires field monitoring with pH and conductivity meters as an "early warning system". Once significant changes are monitored, this would revert to level-two analyses.

5.2.3 Tailings Pore Water

The monitoring of tailings pore water might be necessary to chart the movement of radionuclides and chemicals into surface runoff, infiltration and seepage. Monitoring wells and/or piezometers can be used to sample pore water. Parameters to be measured are the same as those for surface water and groundwater outlined above.

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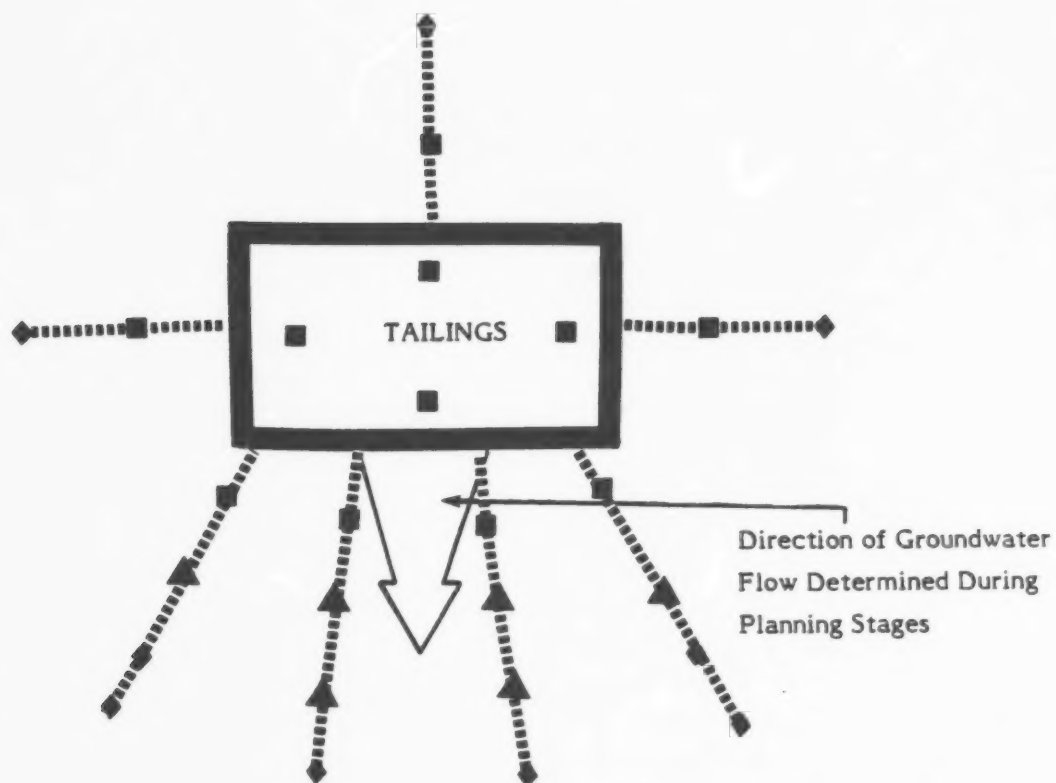
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The first level of monitoring, with wells under the tailings and in the immediate periphery of the tailings site, will be for all parameters outlined in Section 5.2.1 above. The second level of monitoring will be for major ions as an indication of the leading edge of the plume. As soon as these levels rise, the sampling station reverts to first-level analysis. The third level requires field monitoring with pH and conductivity meters as an "early warning system". Once significant changes are monitored, this would revert to level-two analyses.

5.2.3 Tailings Pore Water

The monitoring of tailings pore water might be necessary to chart the movement of radionuclides and chemicals into surface runoff, infiltration and seepage. Monitoring wells and/or piezometers can be used to sample pore water. Parameters to be measured are the same as those for surface water and groundwater outlined above.

FIGURE 5.4: CONCEPTUAL GROUNDWATER MONITORING NETWORK



Monitoring Wells

- - analyzed for all parameters (Level 1).
- ▲ - analyzed for major ions (Level 2).
- ◆ - monitored for pH and conductivity in the field (Level 3).

5.2.4 Frequency of Aquatic Monitoring

Surface receiving waters should be monitored quarterly over the first year after decommissioning to determine seasonal effects. Flow measurements should be taken of significant outflows from the tailings area. Following this, annual monitoring is recommended at low flow in late summer for a further four years. If no adverse pollution is recorded, the frequency could then be dropped to once every two years for the next 5, and then to once every 5 years.

Groundwater sampling should follow a similar, or appropriate, alternative schedule. Measurements of water-table level should also be recorded during sampling.

5.3 Atmospheric Monitoring

5.3.1 Location and Parameters

Atmospheric monitoring stations should be selected in those areas most likely to be impacted upon, as determined through the use of meteorological modelling. An upwind control site should also be sampled. Vegetation sampling should use the same sites.

Ideally, particulates should be collected using a high-volume sampler but, if nearby power is not available, a portable generator or some type of passive monitor may have to be employed. These would be analyzed for radionuclides (U, Ra-226, Pb-210 and Th-230), and for heavy metals.

Gamma radiation should be measured around the periphery and on the surface of the tailings pile. Radon-222 should be measured utilizing track-etch cups, left in the field at stations around the tailings pile and collected one year later.

5.3.2 Frequency

Particulates should be measured with the same frequency as the water sampling program. Other air sampling would follow a similar schedule, except for only one sampling in the initial year.

5.4 Biological Sampling

5.4.1 Sampling Programs

During field investigations, samples should be collected of aquatic biota that may be consumed by people in downstream receiving waters, e.g., fish. Vegetation samples could be collected at air sampling stations as a potential long-term monitor of air pollutants. Biological samples should be analyzed for U, Th-230, Ra-226, Pb-210, Th-232 and Ra-228, and for appropriate trace elements.

5.4.2 Frequency

Biological monitoring should occur twice during the first five years after decommissioning, and at five-year intervals thereafter, unless there is evidence of a significant increase in biological tissue levels. The eventual 5-year monitoring program should continue until there are no further signs of significant quantities of contaminants leaving the tailings site. If monitoring indicates significant increases in environmental contamination, the program should revert to an annual or bi-annual frequency, based on an institutional determination of site-specific risks to public health and the environment.

SECTION 6

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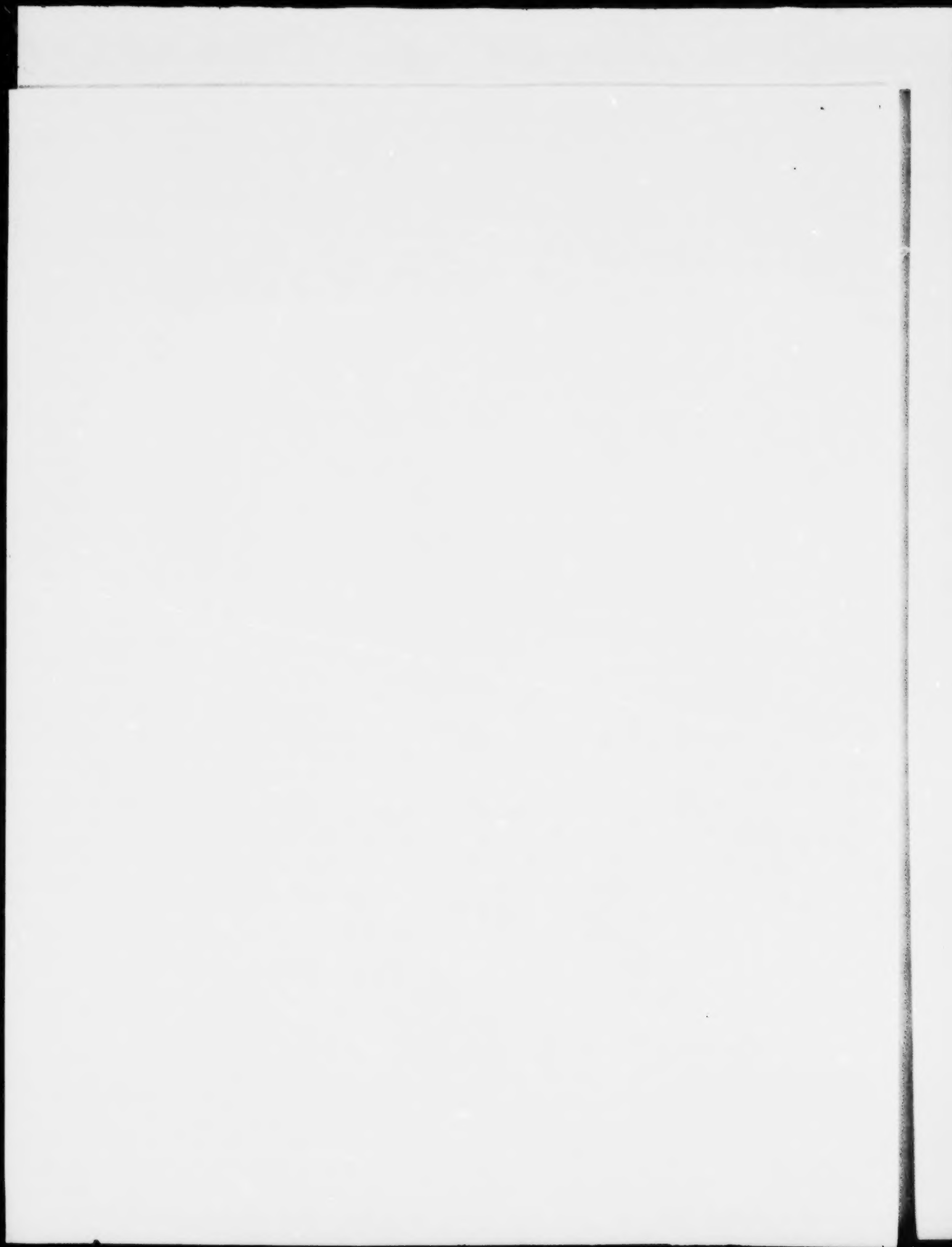
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APPENDIX 1

**DETAILED CALCULATIONS FOR
DECOMMISSIONING COST ESTIMATES**



APPENDIX 1: DETAILED CALCULATIONS FOR DECOMMISSIONING COST ESTIMATES

The approach for estimating decommissioning costs utilized unit costs for a generic tailings facility. An electronic spreadsheet (Multiplan, copyright Microsoft) was used which allows instantaneous calculations once numbers are put in the Number of Units column (Column 7) on the spreadsheet. Table 1 represents the generic table (with 0 in the units column), while Table 2 tests the calculations with a hypothetical 40-ha tailings site (described further below).

The per unit cost estimates were taken from Means (1982) "Building Construction Cost Data, 1982" calculated for Canadian costs and dollars (factor 0.993 rounded to 1) in 1985 dollars (escalated for 3 years at 7% per annum). There is no allowance for a general contractor markup (usually 10%), but subcontractor costs are included.

The generic table (Table 1) incorporates a number of alternative tailings management approaches. In specific cases, the most appropriate one(s) would be used (e.g., one does not use vegetative cover and asphalt cover on the same site). Likewise, some cost categories (e.g., extra berm, extra haulage) are only appropriate to specific cases.

Table 2 represents a hypothetical tailings site used to test the calculations by the spreadsheet. The following assumptions were made:

- o tailings area, 40 ha,
- o a fence around the site and two gates,
- o borrow haulage, 2 km,
- o site remoteness factor, 1,
- o extra berm 1/4 of circumference,
- o topsoil depth, 10 cm, underlain by 30 cm of borrow material,
- o diversion drains, 100 m x 1 m x 1 m,
- o slurry trench, 50 m x 6 m x 1/2 m, with 20% bentonite fill, and
- o rip-rap, 200 sq m x 20 cm.

Table 3 demonstrates the model's reaction to a remoteness factor of 1.5.

TABLE 1:
GENERIC PER UNIT BASIS
RECOMMENDATIONS COSTS
File 2253.2

ACTIVITY	MEAS CODE	GENERAL SPECIFICATIONS	SITE SPECIFIC SPECIFICATIONS	\$ COST	/UNIT	NO. OF UNITS	COST /100 TONNAGE	SITE FACTOR (remote)	SITE COST
FENCING:									
-Security	2.7-11-030	4x prism gr. in concrete		\$117.00	metre	0	10.00	1	10.00
-Industrial	2.7-09-030	2x, 3 str barbed, 3x4 post 63x 6C		\$54.00	metre	0	10.00	1	10.00
RAIL:									
(+ new items)	2.7-09-140	2x, 3x4 frame, gal steel		\$154.00	each	0	10.00	1	10.00
PHYSICAL STABILITY									
-Grubbing	2.1-10-01	clear and grub light trees to 15cm - cut and chip		\$6339.00	ha	0	10.00	1	10.00
EXTRA WORK									
-Common Burrow	2.3-05-020	buy and load at pit, haul 2 ha, place and spread with 2000P drier, no compaction	mine rock at same rate	\$7.30	cu m	0	10.00	1	10.00
-Extra Haulage	2.3-05-090	+ haulage > 2 ha		\$1306.00	ha I ha	0	10.00	1	10.00
-Rehabilitation		+ rehab of borrow site	mine waste not required	\$0.50	cu m I ha	0	10.00	1	10.00
LANDSCAPING:									
		if required on bore							
-Seeding, etc	2.0-05-100	hydraulic seeding of large area incl seed, fertilizer, mulch	complete with tailings cover already placed	\$0.80	sq m	0	10.00	1	10.00
DIVERSION DRAINAGE:									
-Excavation	2.3-15-230	trenches in rock (1300 cu m trenches in rock) 1300 cu m soil with backhoe 1 cu m cap	use spoil for cover on tailings	\$71.00 \$62.00 \$2.15	cu m cu m cu m	0 0 0	10.00 10.00 10.00	1 1 1	10.00 10.00 10.00
-Slurry Trench		if required							
	2.3-05-010	backfill with soil-concrete mix	use on tailings	\$25.65	cu m	0	10.00	1	10.00
	2.3-05-080	dump (2 ha (labour only)		\$7.34	cu m	0	10.00	1	10.00
	2.3-05-090	backfill (if req) (labour only) materials special as required equipment rental	site specific site specific	\$17.75	cu m	0	10.00	1	10.00
-Cover. Roads	1.1-30-050	as req'd, 7cm gravel		\$2000.00	ha	0	10.00	1	10.00
-Big Bag	2.3-30-010	random filter stone dumped from trucks, machine placed slope protection	mine rock if available	\$21.50	cu m	0	10.00	1	10.00
CONCRETE:									
-Contouring	2.3-22-020	with 2000P drier	equipment rental	\$2300.00	month	0	10.00	1	10.00
-Base Course	2.3-05-020	common borrow buy, haul 2 ha to site, spread with 2000P drier, 30cm deep, no compaction, haulage > 2ha	mine waste can be substituted for borrow	\$23000.00	ha	0	10.00	1	10.00
	2.6-02-030	crushed stone: 30cm deep @ 75/tonne		\$1500.00	ha I ha	0	10.00	1	10.00
	2.6-02-030	15cm deep @ 75/tonne		\$63000.00	ha	0	10.00	1	10.00
	2.6-02-040	bank run gravel @ 96/cu m -30 deep -15cm deep		\$20730.00 \$20000.00	ha ha	0 0	10.00 10.00	1 1	10.00 10.00
		compaction with 10 tonne roller		\$47.50	ha	0	10.00	1	10.00
-Topsoil Cover	2.6-10-050	7cm thick @ 125/tonne		\$12370.00	ha	0	10.00	1	10.00
	2.6-10-060	10 cm thick @ 125/tonne		\$113000.00	ha	0	10.00	1	10.00
-Lime or Fopaci	2.0-25-002	remove and store on site, 2000P tractor, 2m deep, 60x haul	labour only	\$1.50	cu m	0	10.00	1	10.00
	1.5-05-025	2000P drier	equip rental	\$2500.00	month	0	10.00	1	10.00
		replace, load, transport, spread	labour only	\$4.30	cu m	0	10.00	1	10.00
-Vegetative Cover		assume cover's prime use is to delay dust, seeded on common borrow							
-Limestone (if req)	2.0-20-060	@ 750/tonne		\$1025.00	ha	0	10.00	1	10.00
-Seeding		@ 630g/ha		\$1375.00	ha	0	10.00	1	10.00
-Fertilizer		@ 550g/ha		\$1500.00	ha	0	10.00	1	10.00
-Organic Seeding		includes seed and fertilizer with wood fiber mulch		\$2300.00	ha	0	10.00	1	10.00
TOTAL COST						COST \$ 0.00E+00		COST \$ 0.00E+00	

TABLE 2:
HYPOTHETICAL TAILINGS SITE WITH REMEDIATION FACTOR 1, 40% AREA
RECOMMISSIONING COSTS
File 2253.2

ACTIVITY	MEANS CODE	GENERAL SPECIFICATIONS	SITE SPECIFIC SPECIFICATIONS	Q COST	UNIT	HL. # UNITS	COST PER TONNAGE SUBTOTAL Q TOTAL Q	SITE FACTOR (tonnage)	SITE COST SUBTOTAL Q TOTAL Q		
FENCING:											
-Security	2.7-11-430	40 prism gr. in concrete		9117.00	extra	2340	2.62E+05	2.62E+05	1	2.62E+05	2.62E+05
-Industrial	2.7-09-050	2x, 3 str barbed, 5cm post 62x 62		954.00	extra	0	0.00E+00	2.62E+05	1	0.00E+00	2.62E+05
RAILS:											
(+ misc items)	2.7-09-140	2x, 5cm frame, gal steel		9134.00	each	2	3.06E+02	2.62E+05	1	3.06E+02	2.62E+05
PHYSICAL STABILITY											
-Grubbing	2.1-10-01	clear and grub light trees to 15cm - cut and chip		94338.00	ha	40	2.62E+05	3.24E+05	1	2.62E+05	3.24E+05
EXTRA WORK											
-Common Barron	2.3-05-020	buy and load at pit, haul 2 km, place and spread with 200HP dozer, no compaction	mine rock at same rate	67.50	cu m	30000	2.23E+05	7.49E+05	1	2.23E+05	7.49E+05
-Extra Haulage	2.3-05-090	= haulage > 2 km		91306.00	ha 1 ha	0	0.00E+00	7.49E+05	1	0.00E+00	7.49E+05
-Rehabilitation		= rehab of barron site	mine waste not required	90.60	cu m 1 ha	60000	3.68E+04	7.83E+05	1	3.68E+04	7.83E+05
LANDSCAPING:											
		if required on bare									
-Seeding, etc	2.8-05-100	hydraulic seeding of large area incl seed, fertilizer, mulch	complete with tailings cover already placed	90.00	sq m	6000	6.00E+02	7.90E+05	1	6.00E+02	7.90E+05
DIVERSION DRAINAGE:											
-Excavation	2.3-15-220	trenches in rock (1300 cu m trenches in rock) 1300 cu m soil with backhoe 1 cu m cap	use spoil for cover on tailings	971.00 962.00 93.15	cu m cu m cu m	100 0 100	7.10E+03 0.00E+00 2.13E+02	7.97E+05 7.97E+05 7.90E+05	1 1 1	7.10E+03 0.00E+00 2.13E+02	7.97E+05 7.97E+05 7.90E+05
-Slurry Trench		if required									
	2.3-05-010	backfill with soil-concrete mix	use on tailings	925.66	cu m	120	3.82E+03	8.61E+05	1	3.82E+03	8.61E+05
	2.3-05-000	dump (2 ha (labour only)		97.24	cu m	120	1.09E+03	8.61E+05	1	1.09E+03	8.61E+05
	2.3-05-090	backhoes (if req) (labour only) materials special as required equipment rental	site specific site specific	917.75	cu m	30	3.32E+02	8.61E+05	1	3.32E+02	8.61E+05
-Constr. Roads	1.1-30-080	as req'd, 7cm gravel		930000.00	ha	5	1.20E+05	9.23E+05	1	1.20E+05	9.23E+05
-Rip Rap	2.3-20-010	random filter stone dumped from trucks, machine placed slope protection	mine rock if available	921.50	cu m	40	1.26E+03	9.24E+05	1	1.26E+03	9.24E+05
COVER:											
-Contouring	2.3-22-020	with 200HP dozer	equipment rental	90306.00	month	1	0.30E+03	9.23E+05	1	0.30E+03	9.23E+05
-Base Course	2.3-05-020	common barrow buy, haul 12 km to site, spread with 200HP dozer, 30cm deep, no compaction, extra haulage > 2km	mine waste can be substi- tuted for barrow	923000.00	ha	40	9.30E+03	1.03E+06	1	9.30E+03	1.03E+06
				91306.00	ha 1 ha	0	0.00E+00	1.03E+06	1	0.00E+00	1.03E+06
	2.6-02-030	crushed stone: 30cm deep @ 95/tonne		903000.00	ha	0	0.00E+00	1.03E+06	1	0.00E+00	1.03E+06
	2.6-02-020	15cm deep @ 95/tonne		93730.00	ha	0	0.00E+00	1.03E+06	1	0.00E+00	1.03E+06
	2.6-02-040	bank run gravel @ 96/tonne -30 deep -15cm deep		930730.00 920000.00	ha ha	0 0	0.00E+00 0.00E+00	1.03E+06 1.03E+06	1 1	0.00E+00 0.00E+00	1.03E+06 1.03E+06
		compaction with 10 tonne roller		947.30	ha	40	1.90E+03	1.03E+06	1	1.90E+03	1.03E+06
-Asphalt Cover	2.6-10-020	7cm thick @ 525/tonne		903730.00	ha	0	0.00E+00	1.03E+06	1	0.00E+00	1.03E+06
	2.6-10-060	10 cm thick @ 525/tonne		9113000.00	ha	0	0.00E+00	1.03E+06	1	0.00E+00	1.03E+06
-Loam or Topsoil	2.8-25-002	remove and store on site, 200HP tractor, 2x deep, 50x haul	labour only	91.68	cu m	40000	6.72E+04	1.93E+06	1	6.72E+04	1.93E+06
	1.5-05-026	200HP dozer	equip rental	90306.00	month	1	0.30E+03	1.93E+06	1	0.30E+03	1.93E+06
		replace, load, transport, spread	labour only	94.30	cu m	40000	1.72E+05	2.10E+06	1	1.72E+05	2.10E+06
-Vegetative Cover		assume cover's prime use is to alloy dust, seeded on common barrow									
-Limestone (if req)	2.8-20-060	@ 72kg/sq m		91825.00	ha	40	4.10E+04	2.14E+06	1	4.10E+04	2.14E+06
-Seeding		@ 630kg/sq m		91575.00	ha	0	0.00E+00	2.14E+06	1	0.00E+00	2.14E+06
-Fertilizer		@ 320kg/sq m		91280.00	ha	0	0.00E+00	2.14E+06	1	0.00E+00	2.14E+06
-Hydraulic Seeding		includes seed and fertilizer with wood fiber mulch		90300.00	ha	40	3.00E+05	2.40E+06	1	3.00E+05	2.40E+06
TOTAL COST							CU m 2.40E+06			2.40E+06	

TABLE 3a
HYPOTHETICAL TAILINGS SITE WITH REDUCTION FACTOR 1.5, 40ha AREA
NEEDS/DESIGNING COSTS
File 2223.2

ACTIVITY	MEANS CODE	GENERAL SPECIFICATIONS	SITE SPECIFIC SPECIFICATIONS	Q COST	UNIT	QL W UNIT	COST PER TONNAGE SUBTOTAL \$ TOTAL \$	SITE FACTOR (remote)	SITE COST SUBTOTAL \$ TOTAL \$
FENCING:									
-Security	2.7-11-000	4x prism gr. in concrete		917.00	metre	1200	2.42E+00 2.42E+00	1.5	3.63E+00 3.63E+00
-Industrial	2.7-09-000	2x, 3 str barbed, 3x4 post 0.5m HC		934.00	metre	0	0.00E+00 2.42E+00	1.5	0.00E+00 2.42E+00
RAILS:									
(+ new (tons))	2.7-00-100	2x, 3x4 frame, gal steel		9154.00	each	2	3.08E+02 2.42E+00	1.5	4.62E+02 2.94E+02
PHYSICAL STABILITY									
-Grading	2.1-10-01	clear and grub light trees to 12x4 - cut and chip		45200.00	ha	40	1.13E+03 2.34E+03	1.5	1.69E+03 7.83E+03
EXTRA WORK									
-Common borrow	2.3-00-020	buy and load at pit, haul 2 km, place and spread with 200HP dozer, no compaction	also rock at same rate	17.50	cu m	30000	2.32E+00 7.02E+00	1.5	2.32E+00 1.12E+01
-Extra haulage	2.3-00-090	= haulage) 2 km		91200.00	ha 2 ha	0	0.00E+00 7.02E+00	1.5	0.00E+00 1.12E+01
-Stabilization		= rehab of borrow site	also waste not required	90.00	cu m 2 ha	60000	2.40E+04 7.02E+00	1.5	3.60E+04 1.10E+05
LANDSCAPING									
		if required on bare							
-Seeding, etc	2.0-05-100	hydraulic seeding of large area incl seed, fertilizer, mulch	complete with tailings cover already placed	90.00	sq m	6000	4.00E+00 7.02E+00	1.5	7.20E+00 1.12E+01
SPHERICAL SHAFTING:									
-Excavation	2.3-13-020	branches in rock (1200 cu m	use spall for cover	671.00	cu m	100	7.10E+00 7.57E+00	1.5	1.07E+01 1.30E+01
	2.3-13-030	branches in rock) 1200 cu m	on tailings	652.00	cu m	0	0.00E+00 7.57E+00	1.5	0.00E+00 1.30E+01
		soil with backfill 1 cu m cap		92.15	cu m	100	2.32E+02 7.57E+00	1.5	4.72E+02 1.30E+01
-Heavy trench		if required							
	2.3-05-000	backfill with soil-concrete mix	use on	925.05	cu m	120	2.00E+00 8.00E+00	1.5	3.77E+00 1.30E+01
	2.3-05-000	deep (2 ha (labour only)	tailings	97.34	cu m	120	1.00E+00 8.00E+00	1.5	1.50E+00 1.30E+01
	2.3-05-090	backfill (if req) (labour only)		917.75	cu m	20	2.32E+02 8.00E+00	1.5	7.70E+02 1.30E+01
		materials special as required	site specific						
		equipment rental	site specific						
-Constr. Roads	1.1-20-000	as req'd, 7x4 gravel		92000.00	ha	5	1.30E+03 2.22E+03	1.5	1.95E+03 1.30E+04
-Sig. Rep	2.3-20-010	random filter stone dumped from truck, random placed slope protection	also rock if available	921.00	cu m	40	1.30E+00 2.22E+03	1.5	1.95E+03 1.30E+04
COVER									
-Contouring	2.3-12-020	with 200HP dozer	equipment rental	92000.00	month	1	0.30E+00 2.22E+03	1.5	1.30E+04 1.00E+05
-Base Course	2.3-00-020	common borrow buy, haul 12 km to site, spread with 200HP dozer, 30x4 deep, no compaction, extra haulage) 2ha	also waste can be sub- stituted for borrow	91200.00	ha	40	2.32E+00 1.00E+04	1.5	1.30E+04 2.70E+04
				91200.00	ha 2 ha	0	0.00E+00 1.00E+04	1.5	0.00E+00 2.70E+04
	2.0-02-000	crushed stone 30x4 deep 0 0.5/tonne		92000.00	ha	0	0.00E+00 1.00E+04	1.5	0.00E+00 2.70E+04
	2.0-02-000	15x4 deep 0 0.5/tonne		92070.00	ha	0	0.00E+00 1.00E+04	1.5	0.00E+00 2.70E+04
	2.0-02-040	bank run gravel 0 0.5/tonne -30 deep -15x4 deep		92070.00	ha	0	0.00E+00 1.00E+04	1.5	0.00E+00 2.70E+04
				92000.00	ha	0	0.00E+00 1.00E+04	1.5	0.00E+00 2.70E+04
		compaction with 10 tonne roller		947.50	ha	40	1.90E+00 1.00E+04	1.5	2.85E+00 2.70E+04
-Asphalt Cover	2.0-10-000	7x4 thick 0 0.5/tonne		90570.00	ha	0	0.00E+00 1.00E+04	1.5	0.00E+00 2.70E+04
	2.0-10-060	10 cu thick 0 0.5/tonne		91200.00	ha	0	0.00E+00 1.00E+04	1.5	0.00E+00 2.70E+04
-Lean or Topsoil	2.0-25-000	remove and store on site, 200HP tractor, 2x deep, 60x haul	labour only	91.00	cu m	60000	6.72E+04 1.00E+04	1.5	1.01E+05 2.90E+05
	1.3-00-020	200HP dozer	equip rental	90000.00	month	1	0.30E+02 1.00E+04	1.5	1.22E+04 2.90E+05
		replace, load, transport, spread	labour only	94.50	cu m	60000	1.72E+00 1.00E+04	1.5	2.58E+00 2.12E+04
-Vegetative Cover		common cover's price use is to allow dist. based on common borrow							
-Livestock (if req)	2.0-20-000	0 720p/ha		91025.00	ha	40	4.10E+04 2.10E+04	1.5	6.15E+04 2.22E+04
-Seeding		0 620p/ha		91575.00	ha	0	0.00E+00 2.10E+04	1.5	0.00E+00 2.22E+04
-Fertilizer		0 220p/ha		91500.00	ha	0	0.00E+00 2.10E+04	1.5	0.00E+00 2.22E+04
-Superphos Seeding		includes seed and fertilizer with wood fiber mulch		90000.00	ha	40	2.40E+00 2.00E+04	1.5	3.10E+00 2.72E+04
TOTAL COST						COST \$	2.40E+06		2.72E+06

APPENDIX 2

**DETAILED CALCULATIONS FOR
POST-DECOMMISSIONING MONITORING COST ESTIMATES**



APPENDIX 2: POST-DECOMMISSIONING COST ESTIMATES

Table 1, Aerial Photography and Interpretation Costs Assumptions:

Cost estimates were developed on a unit-cost basis. This allowed calculations utilizing an electronic spreadsheet. The Multiplan program (c. Microsoft) was utilized in this case. This facilitates revisions or sensitivity analyses, such as changes in frequency of surveys or in parameters monitored, with cost calculations following automatically.

Assumptions:

- o the airphoto key is developed once during the initial year of the survey;
- o aerial photography flights and interpretation occur during each survey;
- o surveys occur 3 times (every second year) for the first five years, twice during the second 5 years and 10 times over the next forty years;
- o costs are not projected beyond 50 years after decommissioning;
- o costs and rates are in 1985 Canadian dollars; and
- o report preparation time and expenses are included in the interpretation cost estimate.

Details:

These assumptions and costs are discussed in report section 5.1.1.

Table 2: Ground-Survey Costs

Cost estimates were based on a unit-cost basis using an electronic spreadsheet as described for Table 1.

Assumptions:

- o Ground surveys are conducted quarterly for the first year, annually for the next four years, twice during the next five years and once every five years thereafter;

TABLE 1. AERIAL PHOTOGRAPHY AND AIRPHOTO
INTERPRETATION COSTS

COST FACTOR	SURVEY UNIT COST (\$)	UNITS PER SURVEY	CYRS 1-5 PER ONE TIME KEYS COST (Hours)	PER TIME INTERPRET. HOURS	SURVEY FREQUENCY DURING YEARS:			COSTS DURING YEARS: (1955Cd. \$)		
					1-5	6-10	11-50	1-5	6-10	11-50
AERIAL PHOTOGRAPHY:										
• Flight	500	0			3	2	10	12000	8000	40000
• Film	625	1			3	2	10	1875	1250	6250
AIRPHOTO INTERPRET:										
• Location	40		24	6	3	2	10	1680	480	2400
• Piping	40		2	2	3	2	10	320	160	800
• Flooding	40		4	2	3	2	10	400	160	800
• Under Shading	40		2	1	3	2	10	200	80	400
• Settlement	40		4	2	3	2	10	400	160	800
• Slope Failure	40		4	2	3	2	10	400	160	800
• Diversions	40		3	2	3	2	10	360	160	800
• Stream Migration	40		4	3	3	2	10	520	240	1200
• Trees and Shrubs	40		8	4	3	2	10	800	320	1600
• Animal Burrowing	40		2	3	3	2	10	440	240	1200
• Revegetation	40		3	2	3	2	10	360	160	800
• Knap	40		2	2	3	2	10	320	160	800
• Water Table	40		3	2	3	2	10	360	160	800
• Human Intrusion	40		2	2	3	2	10	320	160	800
• Fences and Signs	40		8	2	3	2	10	560	160	800
• Soils	40		5	3	3	2	10	560	240	1200
OTHER COSTS:										
• Reporting/Meetings	2500	1			3	2	10	7500	5000	25000
• Expenses	500	1			3	2	10	1500	1000	5000
TOTAL:				(HOURS)				TOTAL COST (Cd. \$):	18450	92250
				(COST PER YEAR)				6175	3690	2306
				(COST PER FLIGHT)				10.92	9.225	9.225

TABLE 2

GROUND SURVEY COSTS PARAMETER	NO. PEOPLE	NO. HOURS	NO. SAMPLES	UNIT ANALYSIS COST	EQUIPMENT RENTAL COST	FREQUENCY (YEARS) IN TIME PERIOD			COST IN		TIME (1985 C\$) 6-10 yr	PERIOD 11-50 yr
						1-5 years	6-10 years	11-50 years	1-5 yr	11-50 yr		
TRAVEL/ACCOMMODATIONS												
• travel time	2	8				8	2	8	6400		1600	6400
• expenses	2					8	2	8	28960		7240	28960
SITE WORK:												
• fencing	2	3				2	2	8	600		600	2400
• signs	2	2				2	2	8	400		400	1600
• erosion	2	5				2	2	8	1000		1000	4000
• diversion channels	2	2				2	2	8	400		400	1600
• human activity	2	2				5	2	8	1000		400	1600
• animal activity	2	2				5	2	8	2500		1000	4000
• vegetation	2	5				5	2	8	1000		400	1600
• covers	2	2				5	2	8	1000		400	1600
• monuments	2	1				1	1	2	100		100	200
• markers	2	1				1	1	2	100		100	200
• weathering	2	4				1	1	2	400		400	800
• geomorphic process	2	4				1	1	2	400		400	800
• access roads	2	2				1	1	2	200		200	400
MONITORING (FIELD)												
• dissolved O ₂	2	1	1		\$20.00	2	2	8	240		240	960
• pH	2	1	1		\$20.00	2	2	8	240		240	960
• levels	2	1	1		\$20.00	2	2	8	240		240	960
• conductance	2	1	1		\$20.00	2	2	8	240		240	960
• temperature	2	1	1		\$0.00	2	2	8	200		200	800
• seepage	2	3	1		\$20.00	2	2	8	640		640	2560
• shear test	2	2	1		\$20.00	0	1	0	0		220	0
• nuclear density	2	2	1		\$20.00	0	1	0	0		220	0
• gamma	2	1	1		\$20.00	1	1	4	120		120	480
LAB SAMPLES:												
• surface water	2	2	5	\$375.00		8	2	8	16600		4150	16600
• porewater	2	2	3	\$375.00		5	2	8	6625		2650	10600
• groundwater (1)	2	12	11	\$375.00		8	2	8	42600		10610	42600
• groundwater (2)	2	6	6	\$110.00		5	2	8	7300		2920	11680
• groundwater (3)	2	12	9	\$0.00	\$20.00	5	2	8	6900		2760	11040
• animal	2	1	4	\$575.00		2	1	8	4900		2400	19200
• soil	2	1	1	\$515.00		1	0	4	615		0	2460
• radon	2	1	1	\$50.00		5	2	8	750		300	1200
• radon flux	2	1	1	\$50.00		5	2	8	750		300	1200
• subsurface radon	2	3	1	\$425.00	\$20.00	1	1	4	320		320	1280
• particulates air	2	2	4	\$515.00		8	2	8	15200		3600	15200
• tellings	2	1	1	\$515.00		1	0	4	615		0	2460
• vegetation	2	4	4	\$575.00		2	1	8	5400		2700	21600
OFFICE WORK:												
• reports/meetings	2	24				5	2	8	12000		4800	19200
• expenses						5	2	8	2500		1000	8000
TOTAL \$:									169355		75750	248160
\$/YR:									33871		11150	6204
\$/TRIP:									33871		27875	31020

- o Due to the site remoteness and decommissioned status, it is assumed the field team will include two persons. Hourly rates (1985) were assumed to average \$50.00 (i.e., one scientist/engineer at \$65.00 and one technician at \$35.00 per hour);
- o Travel time (8 hours return) and expenses were assumed to be constant for each trip, regardless of the number of samples taken;
- o All costs are in 1985 Canadian dollars; and
- o Costs are not projected beyond 50 years.

The design of the spreadsheet will allow lumping of complementary site monitoring activities as experience dictates.

Details

Details on costing assumptions, and the rationale behind them, are provided in report sections:

- 5.1.2 - ground level erosion, geological and revegetation surveys;
- 5.2 - aquatic monitoring;
- 5.3 - atmospheric monitoring; and
- 5.4 - biological monitoring.